Farm-level barriers to the adoption of precision agriculture technologies in the South African maize industry: Variable Rate Application, Section Control, and Guidance

by
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Declaration

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Abstract

This research focuses on the farm level barriers to precision agriculture, specifically guidance/auto-steer, section control, and variable-rate application. The research was focused on the summer rainfall maize producing areas of South Africa. The first objective was to identify adoption rates of PA technology in South Africa, the second objective of the study was to identify the farm level barriers, the third was to quantify the perceived benefits of these three forms of precision agriculture (PA) and the fourth was to establish how farmers manage their machine data and view privacy considerations.

In response to the farm problem as the continual cost-price squeeze, farmers must continually strive to increase their productivity and reduce their input costs. A key component of the response by maize farmers to counteract the farm problem is the adoption of PA technologies. In my sample, the adoption rates were found to be at 65% for guidance, 51% for section control, and 49% for variable-rate application. This compares favourably to the international literature which estimates the aggregate adoption of these technologies at between 29% for VRA and 59% for guidance in maize production. However, the South African adoption rates still leave ample room for improvement especially amongst smaller farms that were underrepresented in this study. Concerning the drivers of adoption this study had inconclusive and, in some instances, contradictory results (e.g., age and education) relative to the international literature. However, I found that farmers who use PA technologies have the perception that the latter technology has clear benefits for productivity and efficiency. Concerning the farmers not using PA, responses were mixed to the extent that it created the impression that this subset of farmers is uninformed about the extent of the benefits and for some farmers the suitability of the technology given the computer literacy of their operators.

The results from the surveys indicate that the perceived benefits of PA technology outweigh that of the farm-level barriers. Farmers should depreciate their capital cost over five to ten years, in terms of feasibility, instead of looking at the initial capital outlay. It is difficult to measure the efficiency improvements in terms of increased productivity and reduced driver fatigue, these variables although intangible, do play a big role in equipment management.

Opsomming

Hierdie navorsing fokus op die plaasvlak hindernisse tot presisielandbou (PL), veral selfstuur, seksiebeheer varieerbare-toediening. Die navorsing het gefokus op die mielieproduserende somerreënvalgebiede van Suid-Afrika. Die eerste doelwit was om die opneemkoers van PL-tegnologieë in Suid-Afrika te identifiseer, die tweede doelwit van die studie was om plaasvlak hindernisse te identifiseer, die derde was om die waarneembare voordele van hierdie drie vorms van presisielandbou te kwantifiseer en die vierde was om te bepaal hoe boere hulle masjiendata bestuur en hulle privaatheidsoorwegings beskou.

In reaksie op die plaasprobleem as voortdurende kosprysdruk, moet boere voortdurend daarna streef om hulle produktiwiteit te verhoog en hulle insetkoste te verminder. 'n Sleutelkomponent van die reaksie onder mielieboere om die plaasprobleem teë te werk, is die aanneem van PL-tegnologieë. In my monster was die aannemingskoerse 65% vir selfstuur, 51% vir seksiebeheer en 49% vir varieerbare-toediening (VRA). Dit vergelyk goed met die internasionale literatuur, wat die saamgestelde aanneming van hierdie tegnologieë skat op tussen 29% vir VRA en 59% vir selfstuur in mielieproduksie. Opneemkoers in Suid-Afrika laat nog heelwat ruimte vir verbetering, veral onder kleiner plase, wat onderverteenwoordig was in hierdie studie. Met betrekking tot die drywers van aanneming, het hierdie studie onbesliste en in sommige gevalle teenstrydige resultate (bv. ouderdom en opleiding) relatief tot die internasionale literatuur verkry. Ek het egter gevind dat boere wat die PL-tegnologieë gebruik die persepsie gehad het dat die tegnologie duidelike voordele bied m.b.t. produktiwiteit en doeltreffendheid. Met verwysing na boere wat nie PL gebruik nie was die reaksies gemeng in soverre dit die indruk geskep het dat hierdie onderafdeling van boere nie ingelig was oor die grootte van die voordele nie en sommige boere nie van die gepastheid van die tegnologie nie, gegewe die rekenaargeletterdheid van hulle operateurs.

Die resultate van die opnames dui aan dat die waarneembare voordele van PL-tegnologieë swaarder weeg as dié van die plaasvlak hindernisse. Boere moet op grond van uitvoerbaarheid hulle kapitaalkoste oor 'n tydperk van vyf tot tien jaar depresieer in plaas daarvan om na die aanvanklike kapitaaluitgawe te kyk. Dit is moeilik om die verbeteringe in doeltreffendheid in terme van verhoogde produktiwiteit en verminderde drywermoegheid te meet. Hoewel hierdie veranderlikes ontasbaar is, speel hulle tot 'n groot rol in toerustingbestuur.

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Chapter 1: Introduction

Farmers must continually strive to maximise productivity and minimise cost given the relentless pressure of the cost-price squeeze. Precision agriculture (PA) enables farmers to increase their productivity since it offers a more efficient resource management system through the combined use of several technologies. Therefore, it is important to research PA to enable farmers to make decisions with improved information on the topic of PA. PA in this study refers to the technology that enables PA as satellite guidance, section control, and variable-rate application, listed in increasing order of technological sophistication.

Formally Olson (1998:2) defines PA as "…the application of a holistic management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with agricultural production, marketing, finance, and personnel characteristics." According to Robert (2002:143), the benefits of PA include improved crop quality; improved sustainability; lower production risk; improved food safety associated with product traceability; environmental protection; rural development through new skills being transferable to other activities.

A crucial stage in the VRA of inputs is the geographic information system (GIS) based process where one or more layers of spatial data are used to configure the prescribed application map of inputs at the optimal rate (Buick, 1997:181). The prescribed application map will be loaded onto the on-board computer which drives the VRA controller. VRA differs from section control and guidance as VRA requires an external source of information in the form of a prescription map to execute VRA while section control and guidance require the technology to execute its objective without the influence of an external factor.

Integrating multiple data sources within a GIS platform allows for the generation of VRA prescription maps that can be executed by machinery fitted with the appropriate hardware. A typical example of VRA use is the site-specific correction of soil pH using a lime applicator and tractor combination fitted with the necessary hardware to allow for the lime application to vary on a per hectare basis (or less) following a prescription map generated from soil sample data. In addition to soil data, VRA prescription maps can be generated for several application types and data sources which include yield maps, hyperspectral and remote sensing data. The spatial and temporal resolution of these data sources varies as a result of differences in collection cost and the frequency of the data needed for decision making (Plant, 2000). Yield monitoring is the process whereby a yield map is constructed by a combine harvester based on the flow rate of material harvested which is linked to its location of collection via a global navigation satellite system, data from yield monitors is only obtained once per growing season however it has a relatively high spatial resolution. Soil sampling data on the other hand, which provides a perspective of the variation in the chemical and physical characteristics of soil, is relatively more expensive since it is time-consuming to collect and analyse, soil sampling is therefore collected at a lower spatial and temporal resolution (Plant, 2000). Soil sampling data is typically obtained before a growing season has started. Both soil sampling and yield monitoring differ from hyperspectral and remote sensing imagery as they acquire data usually once a season, while hyperspectral and remote imaging can be done numerous times throughout a growing season to track the health and growth of crops.

The global navigation satellite system (GNSS) is a key component of PA since it enables farmers to reduce their overlap between implement passes using computer-aided steering systems (guidance/auto-steer) and enable farmers to increase their management resolution from that of an entire farm or field to site-specific management at the sub-field level. GNSS utilises different satellite navigation systems from different organizations such as GPS (American GNSS), Galileo (European GNSS), BeiDou (Chinese GNSS), and other regional systems (Venezia, 2015). These satellite navigation systems triangulate the signals from a constellation of satellites to pinpoint the location and altitude of the GPS receiver on the earth's surface (Plant, 2000). Section control utilizes GNSS information to control implement sectors by means of turning relevant sectors on and off to reduce overlap in previously applied areas (John Deere sub-Saharan Africa, 2020). Variable-rate application (VRA) allows farmers to apply an optimal rate of fertilizer, lime, and seed at a sub-field level thereby improving the efficiency of inputs applied (Thrikawala et al., 1999:926). With the efficient allocation of inputs, a farmer will not only improve crop yields and reduce cost but also their environmental impact (Khosla & Alley, 1999:6).

1.1 The international perspective to PA in maize

The adoption rates for PA technology ranged in terms of what type of PA systems were adopted as well as where they were adopted. A large portion of international literature focused their studies on VRA or site-specific management with a distinct focus on nitrogen fertilizer application. The adoption rates were difficult to quantify as the variables included in defining what PA technology was used were substantial ranging from 29% for VRA to 59% for guidance (Lowenberg-DeBoer & Erickson, 2019). Rodriguez et al (2009:61) summed up the barriers to the adoption of PA technologies being the generation and dissemination of information, economic and social factors, farmer's characteristics, and farm infrastructure conditions. The perceived benefits of VRA also varied, a study done on the maize production area in the United States of America by Griffin et al (2004:11) found that 72% of farmers reported benefits in the application of nitrogen fertilizer, 86% in maize plant population, 60% for the application of phosphorus and potassium fertilizers, 100% for guidance systems, 100% for the VRA of lime and 33% for yield monitoring technology on harvesters.

1.2 The South African perspective to PA in maize

Little is known on the adoption of PA technologies by South African maize farmers, even though the area planted to maize represented 57% of the commercial area in field crops between 1970 and 2015 (Greyling &

Pardey, 2019). In addition to the continued pressure of the cost-price squeeze and international competition, South African maize farmers are under pressure with a significant variance in rainfall over the past decade due to climate change (Nell et al., 2006). Given these challenges the adoption of PA by South African maize farmers, specifically VRA since it integrates the various PA technologies, could improve the long-term profitability and resilience of their operations (Plant, 2000).

There have been limited studies completed on PA in the form of VRA for grain farmers in South Africa. With Robert (2002:143) focussed on using PA for addressing the challenges with crop nutrition management, Rodriguez et al. (2009:60) studying the barriers to adoption of sustainable agriculture practises, and Grant (2003:7) considering the barriers to and strategies with the adoption of PA in nutrient management systems. Jacobs, Van Tol, and Du Preez (2018:107) focused their research on the perceived benefits of adopting PA and the role of agricultural extension in the Schweizer-Reneke region of the North West province of South Africa. They found that the cost associated with converting to PA techniques was the major barrier to adoption in their study area and noted that other significant barriers include usability and understanding of PA technology, management issues relating to PA systems, and fear of change.

It is therefore clear that there have been limited studies relating to PA with an understanding of the adoption rates of PA technology, the farm level barriers to adopting PA technology, the perceived benefits of PA technology as well as how farmers view machine data and the privacy of machine data.

1.3 Objectives

Given the current gap in the literature, the objectives of this study are fourfold: One, what is the current level of PA adoption among a sample of South African maize farmers, specifically variable-rate application (VRA), section control, and guidance technology. Two, what are the barriers to the adoption of PA technology among the maize farmers surveyed. Three, what is the perceived benefit of adopting precision agriculture technology according to the maize farmers surveyed. Four, how do farmers view machine data concerning importance as well as privacy.

These objectives will provide a better understanding of the use of PA by South African maize farmers. This research will illustrate to input and machinery suppliers as well as precision agriculture consultants where they can make advancements in terms of how their products are viewed by farmers and where their shortcomings are in selling PA technology and servicing those systems.

1.4 Hypothesis

The first hypothesis of this study is that the adoption of precision agriculture technologies by South African maize farmers is driven by farmer characteristics such as farmer age, level of education, production attributes, and beliefs regarding PA as found by Rodriguez et al. (2009:62) in the United States of America

The second hypothesis of this study is that the cost of the PA permitting hardware and software is less of an adoption barrier than the expertise needed for the management, manipulation, and processing of the data (agronomic barriers) for the generation of VRA prescription maps and the use of PA technologies.

The third hypothesis is that the adoption of PA technologies is perceived to be cost saving and yield increasing, but also that it decreases yield variability.

1.5 Thesis outline

In the first chapter, an introduction to the study is given as well as a brief overview of the international perspectives of PA to maize production and the South African perspective of PA in maize production. Chapter 1 also contains the objectives of the study and the hypothesises of the study.

Chapter 2 accommodates the literature review of the thesis. The literature review considers the previous studies done on PA concerning maize production and PA technology. The sub-headings in the literature review focus on the barriers to the adoption of PA technology both internationally and in South Africa, as well as the perceived benefits of PA and the adoption rates of PA both internationally and in South Africa. Chapter 3 shows the data acquisition techniques and the method used in this research topic.

Chapter 4 illustrates the results and discussion revolving around the relevant PA adoption levels with a focus on the biographic information of farmers, farm properties, precision agriculture attributes, and the logit model results. Chapter 5 looks at the barriers to the adoption of both VRA and section control. While chapter 6 looks at the perceived benefits of using PA technology. Chapter 7 illustrates the final objective of the study which is how farmers view machine data and the privacy thereof.

Chapter 8 concludes the study with a response to the hypothesis, a synthesis, suggested policy implications as well as suggestions for further research. Chapter 8 concludes the study by answering the relevant questions of what? So what? And what next.

Chapter 2: Literature review

2.1 Introduction

Herbt Dechant, a farmer from Ohio USA, was considered to be a so-called “old-timer” but was forward-thinking in 1999.” *It is my opinion that, no matter how many acres you farm or what type of farm you operate, in order to keep up with current and future demands, you must make it a priority to acquaint yourself with the techniques involved in precision agriculture and begin incorporating them into your method of farming. It is the future for farming*” (Dechant, 1999). Today this future of farming is the reality for up to a third of USA farmers (Schimmelpfennig, 2016).

The original concept in this new era of agriculture started with what was then called “farming by soil type” (the earliest stages of VRA), then later referred to as “site-specific management” (SSM). Today it is more broadly referred to as “PA or precision agriculture”. The earlier concept of site-specific management focused on the application of fertilizers to grain crops in the Midwest, Plains, and Northwest regions of the USA. Today it has been adopted by a variety of different countries who utilize these technology and management systems on a broad spectrum of crops and pastures (Robert, 2002:144). Robert (2002:144) emphasized the growth in PA was not just the improvement in technology but also the way information was managed, which was made possible by the improved technology. This resulted in a more precise farming system. With the improvements in information collection, these data management systems allowed farmers to get a more in-depth understanding of how the crops performed concerning soil surveys, soil sampling, aerial photography, and crop scouting for yield estimates (Robert, 2002:144). A major turning point was the perceived benefits by managing sub-field zones instead of entire fields, this resulted in increased profitability by the more efficient use of inputs as well as increased environmental protection (Robert, 2002:144).

2.2 Benefits and adoption rates internationally

Lowenberg-DeBoer and Erickson (2019) illustrated the adoption rates of PA technology internationally, across four countries including the United States of America (USA), the United Kingdom (UK), Australia, and Denmark. This study included guidance and VRA adoption rates. In 2016, the USA had an adoption rate of 59% for guidance and 29% for VRA in maize production. In 2012 the UK had a smaller range with an adoption level of 46% for guidance and 31% for VRA in cereal production. Still, in 2012, Australia had a higher adoption rate ranging from 49% for VRA and 77% for guidance in the production of cereals while Denmark, did not account for a figure in terms of VRA however they had a 23% adoption of guidance in 2018 (Lowenberg-DeBoer & Erickson, 2019).

In a meta-review of VRA studies in maize, Griffin et al. (2004:11) reported that 72% of articles stated VRA nitrogen application benefits, 86% for VRA of seed, 60% for phosphorus and potassium fertilizers, 100% for

GPS guidance systems, 100% for lime application and 33% for yield monitoring. The adoption rate varies amongst PA technologies in the USA. Yield monitors, which produce geocoded yield maps, is the most widely adopted PA technology in 2004, given that it is used on around 50% of all maize farms, guidance/auto steer PA systems were implemented on 33%, and GPS based yield mapping on 20%. VRA technology and soil mapping systems are used on up to 26% of farms in the study by Griffin et al (2004). On farms over 1100 hectares the study found that 80% utilized mapping systems and guidance systems and around 30-40% used VRA systems (Schimmelpfennig, 2016).

Robert's (2002:143) work was focused on historical PA techniques as well as the implementation of PA, this differs from Rodriguez et al. (2009:60) focus as they narrowed in on the barriers to adopting PA technology while Robert (2002:143) has studied the implementation of PA technology. The capability of the technology has improved year on year, with up to a 40% adoption rate in 2002 (Robert, 2002:144) and 14 years later, in 2016, the adoption of auto-steer/guidance was 59% (Lowenberg-DeBoer & Erickson, 2019).

Robertson, Carberry, and Brennan (2009:799) took a different approach by considering the economic benefits of adopting VRA technology to Australian grain (predominantly wheat) farms. To research this Robertson, Carberry, and Brennan (2009:799) used four farms as case studies and focused on the application of VRA to fertilizer on those four different farms. These farms stretched across the Australian wheat belt and covered a range of agro-climatic regions, cropping systems, farm sizes (1250-5800ha), soil types, and average yield. All four farmers in this case study had conducted some form of VRA strategies in the past 2-10 years. The capital investment in VRA technology by each farm ranged from 37 000AUD to 73 000AUD which translated to a cost per cropped hectare of between 11AUD and 30AUD per year. The estimated benefits of VRA technology ranged from 7AUD per hectare per year to 22AUD per hectare per year. The benefits of VRA varied significantly across fields depending on the intra-field variability. The yields varied substantially within a farm and between farms, with some farms low yields starting at 19 kg/ha and others reaching a high yield of 2100 kg/ha. The mean, however, was just over 1000kgs per hectare (Robertson, Carberry & Brennan, 2009:805). Only one of the four farmers implemented VRA technology to reduce input costs while the other three increased their total fertilizer cost by trying to boost yields and get the maximum potential from the land. The benefits could be estimated within a given paddock from year to year, it was thus noticeable that benefits although diminished, still occurred in years of below-average rainfall. This interprets that once a given zone is identified, benefits from VRA technology occurred in most seasons (Robertson, Carberry & Brennan, 2009:806).

Thrikawala et al. (1999) studied the economic feasibility of VRA technology on corn in a similar focus to that of Robertson, Carberry, and Brennan (2009). Both Thrikawala et al. (1999) and Robertson, Carberry, and Brennan (2009) focused on the VRA of fertilizer and the feasibility thereof. The study was conducted by comparing three different fertilizer strategies namely: constant rate, three-rate strategy, and multiple rate strategy (Thrikawala et al., 1999). Both the three-rate and multiple rate strategies are forms of VRA, the three-rate strategy being a simplification of the multiple rate option. The study was conducted under different probabilities for field fertility. The results varied for different variances in infield fertility. The constant rate application (single rate) was more profitable than the VRA strategies in fields with homogenous fertility and low variance of fertility on an intra-field basis (Thrikawala et al., 1999:924). The economic benefits of VRA technology were prevalent when intra-field fertility distribution was present. VRA technology improves the groundwater quality in low fertility fields by reducing the total fertilizer applied so that fertilizer isn't leached into the underground water system, and improves the yield of corn in areas of high potential (Thrikawala et al., 1999:924).

Anselin, Bongiovanni, and DeBoer (2004) researched a spatial econometric approach to the economics of site-specific nitrogen management in corn production. The resulting objective of this study was to determine the potential for implementing the spatial econometric analysis of the combine yield monitor data to estimate the site-specific crop responses (Anselin, Bongiovanni & DeBoer, 2004:675). This study was conducted in Argentina, South America, where the implementation of VRA required inexpensive information with a focus on inputs as well as common variability in Argentina (Anselin, Bongiovanni & DeBoer, 2004:675). Spatial models were used in the study which consistently indicated profitability where non-spatial models never indicated profitability. One of the constraints mentioned by Anselin, Bongiovanni, and DeBoer (2004) was the difficulty to analyse the data of spatial crop and livestock data. Again, the gap between data analysis and the recommendations on optimal rate of seed, fertilizer, pesticide and other inputs illustrates that information management and implementing the relevant information is a barrier effecting the adoption of VRA technology. Anselin, Bongiovanni and DeBoer (2004) studied the ability to calculate the gains for VRA via the analysis of the combine yield monitor and site-specific application maps. This viewed another economic approach to analysing VRA compared to that of Thirkawala et al. (1999) and Rodriguez et al. (2009).

A study was completed in Pakistan on the effect of variable rates of nitrogen and phosphorus fertilizers on the growth and yield of maize. Although this study used single rate applications across a variety of different combinations of fertilizers which is not aligned with my study on PA, the fact that Pakistan only produced 1.2 million tons of maize at an average yield of 1.4 tons per ha average across the country was interesting. It leads to the major talking point in terms of raising yields which were placed on improving the way and the idea behind fertilizer application (Maqsood et al., 2001:19). Doerge (2005) studied the importance of nitrogen measurement for VRA of nitrogen fertilizer management in maize. Another article relating to VRA and focusing on nitrogen fertilizer management in specific. Doerge (2005) confirms the low adoption levels worldwide of VRA despite the potential economic and environmental benefits of these technologies and the ready availability of PA hardware and software (Doerge, 2005:23). Doerge (2005) has created an observation that a major obstacle in implementing VRA is finding the recommended fertilizer rates on yield goals and that these goals are often poorly correlated to the optimal rate of fertilizer required (Doerge, 2005:23). This statement similar to my hypothesis which states that agronomical barriers are more significant than perceived. Tailoring nitrogen rates to meet the needs of the crop increases the probability of increased profit and reduce environmental risk.

Doerge (2005) highlighted two challenges; the potential cost savings being minimal, vs conventional rates of nitrogen fertilizer applied, the strategy of variable-rate nitrogen application typically has economic benefits of between 12-37% per hectare. Prescriptive nitrogen strategies involve risk. Prescriptive strategies are not yet complex enough to include unexpected variables in-season weather risks such as hail or drought (Doerge, 2005:28) Some recommendations made by Doerge (2005) are based on having so-called “check-strips”, this includes single rate application of nitrogen on strips in the field to assess the yield variability between the two application strategies (Doerge, 2005:28).

2.3 Benefits and Adoption rates in South Africa

The majority of the literature on VRA technology focuses on the effects of nitrogen fertilizer application, more specifically on yield and profit. Nitrogen is essential in the formation of protein in the plant which makes up the majority of the tissue of most living things. Therefore, nitrogen is considered the most vital nutrient and plants absorb more nitrogen than any other nutrient (The Fertilizer Institute, 2014).

A study completed by Maine et al. (2010) on VRA in South Africa focused on the impact of VRA of nitrogen on yield and profit. This study focused on the alternation between VRA and single rate application (SRA). They focused on the impact and feasibility of VRA of nitrogen application, the barriers mentioned include the potential economic returns from the investment, environmental impact, and the degree of risk involved in farming. Farmers will only venture into PA technology if it makes financial sense, this can either be done by reducing costs or increasing the value of the production or yield(Maine et al., 2010). Agriculture is facing a cost-price squeeze which is forcing farmers to be more efficient and sustainable, PA and VRA in specific is one way in which farmers can improve efficiencies (Davis, Cassady &Massey, 1998).

The study conducted by Maine et al. (2010) viewed the relationship between yield as a dependent variable and different rates of nitrogen as the explanatory variable under South African conditions in the Free State province near Bothaville. This is one of the major maize production areas in South Africa. Soil depth was also included as an independent variable in yield. The study was completed over three years and the overall objective was to determine the profitability of VRA of nitrogen on maize in the Free State (Maine et al., 2010). This differs from my primary objective which focuses on the barriers and challenges to implementing VRA along with other PA techniques with a secondary focus on the perceived benefits of using these technologies.

A farmer will only and can only continue to farm if he has a positive return on his investment (Plant, 2000). PA focuses on increasing profitability and returns on investment of inputs by utilizing resources more efficiently. Traditionally a farmer would look at his field and identify the poorer areas and the better performing areas. Without the basic PA technology in yield mapping, the farmer is unable to determine whether it is worth farming those poorer areas as well as the discrepancy between the poorer areas and the better performing areas (Rüsch, 2001:8). Rüsch (2001:8) illustrated the ability for farmers to make more informed decisions on what lands and what areas of certain lands contribute to profit and which areas erode profit. Knowing your input cost per ha and average yield the farmer can work out a cost to income ratio of the gross revenue for a field. The farmer will then be able to work out what percentage of the field area is not contributing to farm income. The farmer has the ability to exclude that area or convert it for different use in which it will be more suitable (Rüsch, 2001;9).

Maine et al. (2010) conducted two sensitivity tests that determined whether their results were robust or not. A partial budget was used to calculate the economic benefits of VRA as a supplement to the SRA. The costs that changed were the price of the PA equipment and nitrogen fertilizer, other inputs including seed, chemicals, other fertilizer, and land costs remained constant, with results favouring VRA of nitrogen fertilizer. The benefits from year to year vary and in some years SRA nitrogen fertilizer was more profitable than VRA. Along with this soil depth was deemed relevant to management zones within a given field as the VRA maps approximated yield maximising levels for nitrogen application. The major factors directly determining the profitability of VRA of nitrogen were farm size and the price of maize, however, nitrogen fertilizer cost, as well as PA equipment costs, also come into consideration as a determining factor for profitability indirectly (Maine et al., 2010).

Half of the farmers in the Schweizer-Reneke area that were included in the case study compiled by Jacobs, Van Tol, and Du Preez (2018) practise precision agriculture by applying VRA of fertilizers and lime to balance the soil fertility. Most of these farmers had also been using these technologies for more than four years. The variable application rates of the major fertilizer's nitrogen (N), phosphorus (P), and potassium (K) have been considered the major reason for adopting the approach of precision agriculture technology and VRA in specific. As mentioned earlier, nitrogen is essential in the formation of protein in the plant which makes up the majority of the tissue of most living things (The Fertilizer Institute, 2014). Due to this, the application rates of nitrogen are based on the estimated yield for a healthy plant. South Africa generally has poor levels of phosphorus in the soils, therefore the majority of the farmers using VRA on fertilizer applications focus on nitrogen and phosphorus. South Africa inherently has high soil potassium levels and that’s the reason why the adoption of VRA in terms of potassium fertilizer is only 33% compared to 94% in nitrogen and phosphorus application of farmers that have adopted PA technology (Jacobs, Van Tol & Du Preez, 2018).

2.4 Barriers to adoption internationally

According to Robert (2002;143), the barriers to the adoption of PA technology by farmers can be grouped according to three main themes: socio-economic, agronomic, and technological barriers. Socio-economical barriers predominantly stem from input costs and the lack of skills to operate PA technology. Agronomic barriers stem from inadequate information, sampling, and scouting procedures as well as the misuse of the information gathered. Technological barriers pertain to technical challenges with the implementation of technology, this includes challenges with machinery, sensors, GNSS, remote sensing, and software used.

Rodriguez et al. (2009:61) mentioned that previous barriers to the adoption of sustainable agricultural practise (SAP) were generational, dissemination of information, economic and social factors, farmer's characteristics, and infrastructure conditions. SAP and PA were two different terms used in research by Rodriguez et al. (2008:61) and Robert (2002:143), however, both these focus on information technology as well as the knowledge in understanding said information technology. The barriers and challenges to adopting SAP are rapidly shifting with a larger focus placed on knowledge and information needs and the lack of available information to farmers in a readily available and understandable format. The inadequate information, which does not comprehensively outline the technical details and specifics around SAP and the impacts of new technologies, often leaves farmers reluctant to practice these methods. Economic factors are the first barrier that comes to mind when thinking about the adoption of PA technology, these economic factors include the cost of purchasing both the hardware and software for PA, the uncertainty over risk and profitability, loss of productivity during the transition period, labour risk, farm policies, and the possible skills development cost to educate the operators on how to use PA technologies. Rodriguez et al. (2008:61) discussed the possible disadvantage surrounding PA due to labour being scarce, expensive, or both in a first-world environment. Another barrier that Rodriguez et al. (2008:61) perceive about SAP is the risk during the transition to SAP from conventional practices.

Rodriguez et al. (2008) study focused on the barriers to the adoption of SAP. Conventional planting and agricultural practices have in the past lead to environmental degradation, social conflict, and economic complications (Rodriguez et al, 2009:60). VRA of inputs is aligned with nutrient management which is a factor in SAP. SAP includes but is not limited to forms of farming such as crop rotation systems, no-till and minimum-till farming, soil conservation, integrated pest management, and managing water quality (Rodriguez et al., 2009:61). The more basic steps of SAP that relate directly to VRA is soil conservation and a fundamental aspect of this being soil testing/sampling. Rodriguez et al. (2008), identified the major barrier to farmers implementing soil testing being economic obstacles. A total of 24% of corn growers stated that soil tests were not conducted due to the cost. With the availability of soil samples, it allows the farmer to practice informed decision making on nutrient planning for the upcoming crop as well as the future.

Of the SAP implemented by farmers in this study by Rodriguez et al. (2009), 37 respondents conducted some sort of soil conservation including nutrient management, soil structure management, erosion control, or any other form of soil conservation. This was the major SAP applied in Rodriguez et a. (2009) study. The second most popular SAP was water conservation with eighteen respondents and livestock management with sixteen respondents (Rodriguez et al., 2009:64).

Rodriguez et al. (2008) study illustrated that 43% of respondents were supporting some form of SAP while less than 25% believe that SAP is available to a great extent in their state (Rodriguez et al., 2009:65). The major challenges and barriers relating to SAP were divided into eight categories namely: economics; education and information; resistance to change; social considerations; infrastructure, landlessness; personal characteristics. 56% of responses indicated economic issues as a barrier with the focus on capital expenditure of the equipment. 53% of responses identified education and knowledge as a barrier to the adoption of SAP with the focus revolving around the lack of education/knowledge and the lack of information. 24% of responses stated that they were resistant to change, and the use of technology was the strong cause for this resistance. 16% of responses indicated that social considerations were a barrier to implementing SAP, change in beliefs, perceptions of inefficiency, lack of farmer examples, and misleading perceptions where the social considerations in focus. A total of 9% of responses highlighting infrastructure as a barrier, 7% of responses highlighting Landlessness as a barrier, and 3% indicating that personal characteristics were a barrier to implementing SAP, 2% of the 3% linked to age.

The striking statistic from Rodriguez et al. (2009) study is the percentage indicating that personal characteristics were a barrier to adopting SAP. One of the hypothesises regarding the barriers to the adoption of new technology is that older farmers could be more reluctant to adopt such technologies, however, it was found that resistance to change was not related to age since only 2% of respondents indicated that age was a barrier to implementing SAP (Rodriguez et al., 2009:66). The most frequently mentioned barrier to the adoption of SAP was a reluctance to change, although it was mentioned on numerous occasions, the issue was not fully explained by respondents. Reluctance to change to SAP is an overused reason for not changing to SAP that tends to hide the real barriers to change that we seek to find out in the survey (Rodriguez et al., 2009)

In terms of recommendations from Rodriguez et al. (2009), SAP needs to have a greater support system from primary and traditional sources, this is currently limited by funding, nonetheless, data from current research should illustrate a better picture in terms of SAP. The allocation of sustainable practices subsidies and incentives will also aid in the implementation and adoption of SAP. Rodriguez et al. (2009) also explain the importance of study groups and extension agencies (officers) which allows for the focus on these issues at a relatively cost-effective and sustainable level. An improved information management system of the existing data on SAP will allow relevant information to be available to farmers. Farmers however can't be criticized about the non-adoption of new technologies, their decision of non-adoption may very well be rational due to current circumstances and conditions (Rodriguez et al., 2009:70).

Important observations found by Robertson et al. (2009) were that all farmers interviewed were highly literate in the use of GPS systems, computers, and VRA controllers. Their soils were routinely tested, and good farm records were kept from each field. The farmers spent time and a considerable amount of effort in setting up their systems. The way they implemented their VRA differed in terms of consultants for zone definition, yield map processing, and the production of VRA maps. Another observation is that many farmers are testing VRA technology in strips on their farm however only a handful are adopting it 100% in their farming enterprise (Robertson, Carberry & Brennan, 2009:806). This study demonstrated that Australian grain producers have adopted VRA technology and have been able to recover their initial outlay within a few years. Intangible benefits were also mentioned but could not be quantified, these are based on driver fatigue, implement productivity, and operator efficiency. The results help the debate for PA, however, PA and VRA still vary from farm to farm as well as between farmer's preferences, circumstances, and attitude towards change (Robertson, Carberry & Brennan, 2009:806).

2.5 Barriers to adoption in South Africa

Jacobs, Van Tol, and Du Preez (2018:107) compiled a case study focusing on the farmer's perceptions of precision agriculture and the role of agricultural extension, this is a case study on crop farming in the Schweizer-Reneke region. The questions involved included the adoption and nature of precision agriculture, the costs involved with adopting precision agriculture, the sustainability of precision agriculture, and suggestions to improve precision agriculture in the study area (Jacobs, Van Tol & Du Preez, 2018:107). The study focused on the Schweizer-Reneke area where my study focuses on the larger maize producing area including the Free State, Kwazulu-Natal, and Mpumalanga. The idea behind studying the entire summer rainfall maize producing area is to test if there is any correlation between the climatic environment in different provinces and the adoption of PA technology. The study above also highlights that in general, it is considered that old farmers are less likely to adopt PA technology (Jacobs, Van Tol & Du Preez,2018:110). There were two previous studies by Matela (2005) and Helm (2002), both of these studies found that farmers over the age of 45 were less likely to adopt new technology when compared to farmers under the age of 45. Jacobs, Van Tol, and Du Preez (2018:110) found no difference in the willingness to adopt new precision agriculture technology between the ages of 31 – 35, 41 – 45, and 51 – 55 years of age. It was only the category of 56 years of age and older that were found more reluctant to accept new technology (Jacobs, Van Tol & Du Preez, 2018:110).

Farmers with tertiary education or more were found to be more likely to adopt new technologies (Matela 2002; Helm 2005). However, in the study of the 36 farmers around Schweizer-Reneke, farmers with a single tertiary degree were less likely to adopt precision technology than farmers with a matric, diploma, or a master's degree. The relationship between the size of a farm's cultivated area and the adoption of technology was highly correlated. Farmers who cultivated less than 500ha of land did not adopt precision agriculture technology, with farmers who cultivated an area less than 1500ha there was a considerable lack in accepting PA technology, while farmers who cultivated more than 3000ha did implement PA practises on their farms (Jacobs, Van Tol & Du Preez, 2018:110). A total of 44% of the farmers modified equipment that they already possessed, while not one farmer had to buy a new combine or tractor, GPS systems were retrofitted onto them. All the farmers that used PA techniques agreed that it made economic sense with all of them covering their costs to convert to a PA system within two years, with some even covering their costs in one year. Economies of size were certainly applicable in this area with fixed costs being divided over a larger number of hectares leading to a cheaper rate (Jacobs, Van Tol & Du Preez, 2018:111).

The cost associated with converting to PA farming techniques was the major barrier to adoption in the area of Schweizer-Reneke, the other noticeable barriers included technology usability and understanding, management issues, and fear of change. A total of 61% of the farmers that have not implemented PA techniques showed interest in converting to PA techniques in the short to medium-term future. The farmers that have already converted to PA highlighted the sociological issues such as "fear to change" and management issues as important factors during conversion while those farmers that have not adopted PA focused their decision mostly on physical aspects such as costs, small and uniform fields instead of the sociological reasons mentioned above (Jacobs, Van Tol & Du Preez, 2018:107).

2.6 Conclusion

What was interesting in the case study in the Schweizer-Reneke area was that those farmers who did practise PA were also inclined to be more sensitive to conservation than those who did not. The farmers that were more inclined to practise PA also used minimum tillage techniques, controlled traffic, and deep ripping. In terms of the soil fertility, 94% of farmers that adopted PA techniques agreed that problem areas in their fields had been improved and 89% of these farmers stated that they didn't increase their fertilizer application but instead the improvement in their "bad areas and reduced yield variability with the efficient application of inputs across the field. Only 6% of the farmers that had implemented PA had reduced their workforce, while 83% indicated that their operators required additional skills and had to be trained. These trained operators would now be paid a higher salary. This is positive in terms of employment and the AgriSETA act for skills development. AgriSETA creates and promotes opportunities for social, economic, and employment growth for agri-enterprises through the relevant, quality, and accessible education, training, and development in both primary and secondary agriculture, in conjunction with other stakeholders in agriculture.

The profitability of PA techniques and technology is the most important consideration, pending the implementation of these systems, this is the deciding factor whether technologies will be adopted or not. The environmental benefits when viewed solely are not a cause for change towards PA, instead, it is a secondary benefit as profitability supersedes environmental benefits in South Africa. This could change if the department of agriculture, forestry, and fisheries (DAFF) passed incentives or policies for the use of SAP.

Chapter 3: Data and Methods

3.1 Data

During the 2018/19 season, South Africa produced 10.5 million tons of maize. During that season the Free State accounted for 38.7% of production with just over 4 million tons, followed by Mpumalanga with 24.8%, the North West with 15.5%, the Northern Cape with 6.4%, Kwazulu-Natal with 6.1%, Gauteng with 5.4%, Limpopo with 2%, the Eastern Cape with 0.9% and the Western Cape with 0.3% (SAGIS, 2020). These ratios vary from year to year in response to the area planted, rainfall, and other climatic factors, nonetheless, the rank in productivity per province remains constant. During the 2016/2017 maize season, the Free State accounted for 44% of total production, Mpumalanga slightly lower with 20%, North West with 19%, The Northern Cape and Kwazulu-Natal both with 4%, Gauteng with 5%, Limpopo with 3% and the remaining 1% split between the Eastern Cape and the Western Cape (SAGL, 2017). The focus region for this study encompasses around 86% of the total production of maize in South Africa including the Free State, Mpumalanga, North West, and Kwa-Zulu Natal. Annual rainfall has a strong correlation to maize production in the summer rainfall areas of South Africa. Figure 3.1 illustrates the annual rainfall across South Africa. Figure 3.1 indicates why the relevant provinces were chosen for the study of maize production.

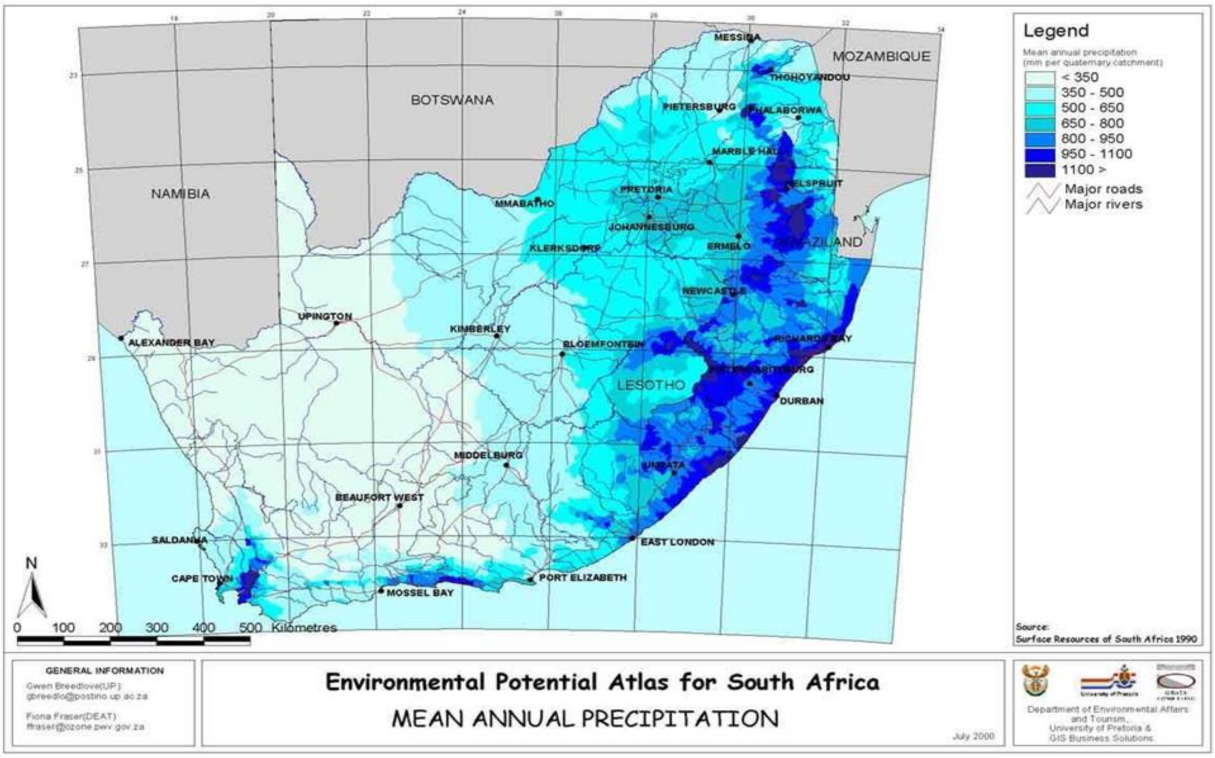

Figure 3.1 Annual rainfall for South Africa (DAFF, 1990)

The objective was to survey 30 maize farmers of different sizes across the respective maize producing areas of South Africa. To this end, a structured survey was compiled (Appendix A – English, Appendix B - Afrikaans) and the original objective was to approach farmers at random at conferences and farmer's days to complete surveys. This technique aimed to randomly select farmers that are not from a certain study group or specific area to create no bias in terms of selection. However, all of these organised gatherings were cancelled following the COVID-19 pandemic. Farmers were either interviewed in person (before lockdown) or telephonically (during lockdown), with some participants opting to complete the survey electronically via email. A total of 30 surveys were obtained with this strategy. In the second round of data collection, members of Grain SA were invited to participate in the study using an online questionnaire, this yielded seven more surveys. It is worth mentioning that six of the seven (86%) self-selected participants made use of PA technology whereas only 17 out of 30 (57%) randomly sampled farmers made use of PA, thus illustrating the challenges with self-selection.

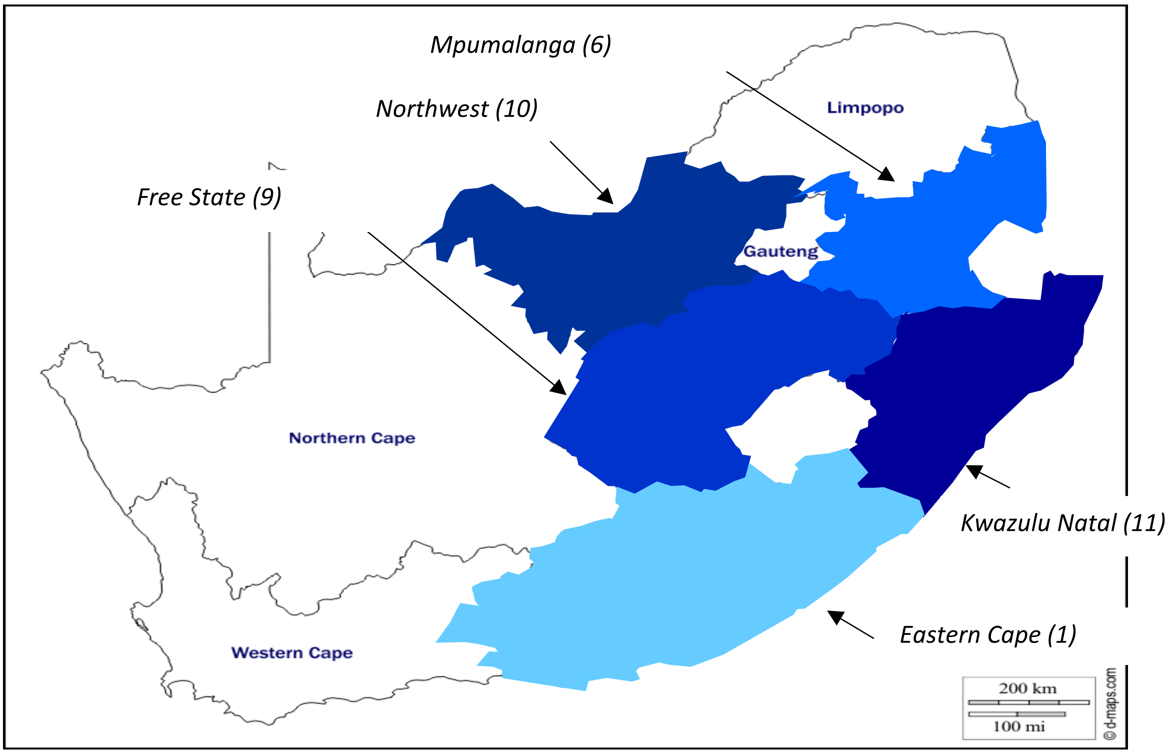

Figure 3.2: Provinces where surveys were conducted with the number of surveys in each province in brackets.

Concerning location, ten surveys were collected in the Northwest, one in the Eastern Cape, nine in the Free State, six in Mpumalanga, and eleven in KwaZulu-Natal. There was a good variance between the location in terms of surveys completed in different municipalities with the maximum being five surveys from Tswaing and four from Ditsobotla municipalities, the remaining twenty-eight surveys spread between sixteen municipalities.

3.2 Insights into regional farming systems in response to climatic conditions.

This study employs descriptive statistics, ANOVA analysis, and a logit model. The data is characterised into two categories for statistical analysis, the first being two-dimension histograms for both yes/no answers as well as questions that require input from the farmer (hectares planted, etc.). The second category is those questions whereby multiple selections were available.

ANOVA (Analysis of Variance) is a statistical tool used to measure the differences in means among more than two different groups. The ANOVA analyses view the variance in the data and where that variance is found. ANOVA focuses on the amount of intra-group variance as well as inter-group variance. ANOVA makes use of three assumptions, namely: the response is normally distributed; the variance is similar within different groups; the data points are independent (Hindle, 2013).

The ANOVA analysis was used to identify the relationship between variables and the use of PA technology. The variables included are age, education, farm turnover, mixed farming practises, hectares planted under irrigation in the 2017/2018 season, and hectares planted under dryland conditions for the season of 2017/2018.

Table 3.1: List of independent variables used in the LOGIT model analysis.

Independent Variables	
Code	**Description**
year born (age)	Age of the farmer
Farm location (province)	Farm location in terms of province
education	The education level of farmer
turnover	Whole farm turnover
Mixed farming	Mixed farming operations
2017/2018 hectares	Hectares of maize planted
The above-mentioned variables are the independent variables used in the study	

A logit model is a predictive statistical analysis tool. It is used to describe data as well as explain the relationship between one dependant dichotomous (binary) variable and one or more nominal, ordinal, interval, or ratio level independent variables (continuous) (Statistical Solutions, 2019). The logit model allows the researcher to evaluate the dichotomous variable without the risk of misinterpretation. A logit model can also be presented in such a way that it can be intuitively understood by the layperson (Walsh, 1987:178). We would be violating the model if we force these regressions into a straight line. No other technique will allow the researcher to analyse the effects of a set of independent variables on a dichotomous dependant variable (Walsh, 1987:178).

In a regression analysis, the key component is the mean value of the outcome variable, given the value of the independent variable. The quantity that we look for is known as the conditional mean which is expressed as $E(Y|x)$ where Y explains the outcome variable and x denotes the value of the independent variable. The quantity of $E(Y|x)$ is the expected value of Y given the value of x (Hosmer & Lemeshow, 2012:5). In linear regression, we express the conditional mean in a linear equation for x such as:

$$E(Y|x) = \beta_0 + \beta_1 x$$

Some well-known cumulative distributions have been used to provide a model for *E(Y|x)* however when the value of Y is dichotomous, the logit model will be used. The two reasons for implementing a logit model encompass the mathematical point of view as it is flexible and is an easy to use function Secondly, it lends itself towards a clinical and meaningful interpretation (Hosmer & Lemeshow, 2012:6). To understand the notation, we use the quantity as *∏(x)=E(Y|x)* to represent the conditional mean of Y given x when the logit model is applied. The specific equation of the logit model is:

$$\pi(x) = \frac{e^{\beta_0+\beta_1 x}}{1 + e^{\beta_0+\beta_1 x}}$$

A transformation of *∏(x)* is utilised so that *g(x)* possesses the desirable properties of a linear regression model. The logit model of *g(x)* is linear in its parameters, however, it may be continuous and range from -∞ to +∞. The transformation to *g(x)* can be seen as:

$$g(x) = \ln[\frac{\pi(x)}{1 - \pi(x)}]$$
$$= \beta_0 + \beta_1 x$$

The dichotomous dependent variable in the logit model is the use or non-use of PA technology by a farmer. In this study, the use of PA technology would be 1= yes, and non-use 0=no. This model uses the maximum likelihood procedures that are not dependant on the normality assumptions of classical regression for either dependent or independent variables (DeMaris, 1992). The logit model measures the natural log of the odds or the log odds of falling into one of the two discrete categories mentioned above (PA use or non-use). Table 1 shows the independent variables included in the logit model.

Chapter 4: PA adoption: Results and discussion

4.1 Biographic information:

4.1.1 Age

The age of participants varied between 24 years and 66 years old. The median age was 46 with a mean age of 44. These figures show that there is a partial split of generations with 5% of farmers between the age of 35-40 and 8% of farmers from 40-45 years of age from the survey. We can consequently see farmers above the age of 45 and 50 years old starting to farm with their children while those farmers between the age of 35 and 45 years old have most likely taken over if they originally started farming with their parents. The data follows through with the experience category as there are 8% and 11% of farmers with experience between the years of 15-20 and 20-25. From the literature, it is expected that younger farmers would be more inclined to adopt new technology as shown by Jacobs, Van Tol, and Du Preez (2018), this was also confirmed by Helm and Matela (2005;2002) who showed that farmers over the age of 45 were less likely to adopt new technology compared to those farmers under the age of 45 years old. Jacobs, Van Tol, and Du Preez (2018), found that there was a lower likelihood of farmers over the age of 55 years old adopting PA technology. This shows the difference in results from Helm and Matela (2005;2002) and Jacobs, Van Tol, and Du Preez (2018) as the older farmers started showing a higher level of adoption from 2018 compared to 2002. Figure 4.1 shows the relationship between age and the use of VRA as found by this study. It shows that contrary to the

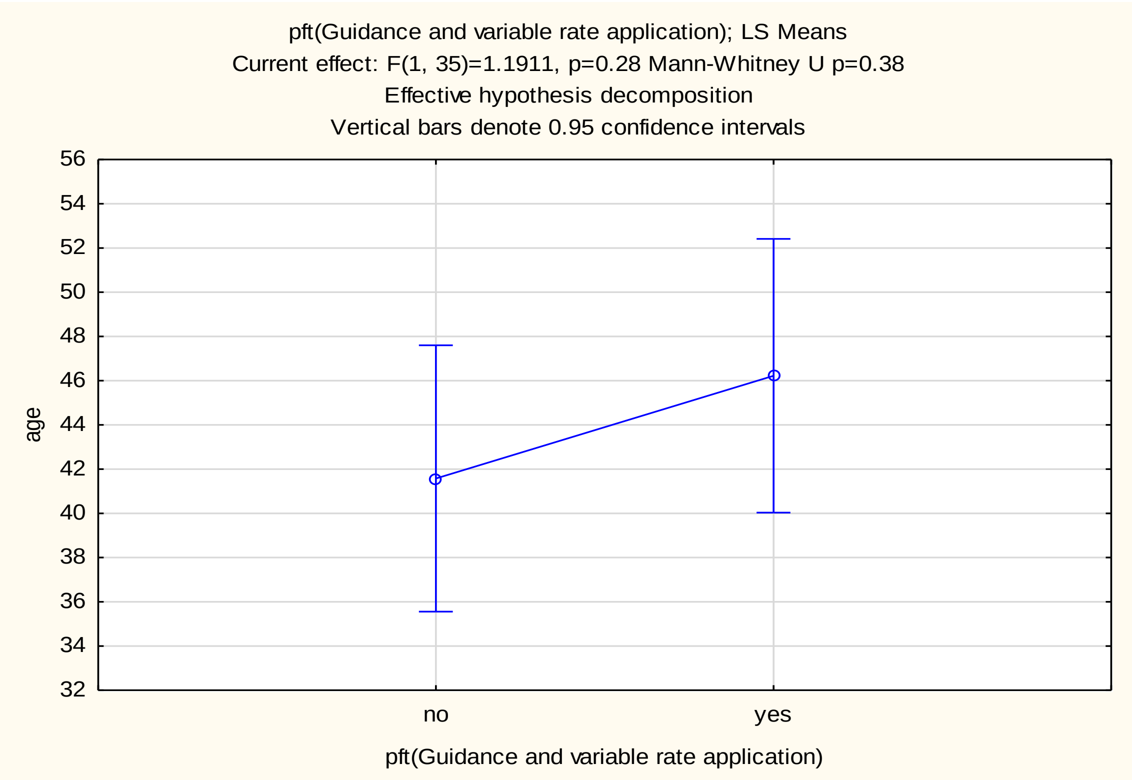

Figure 4.1: ANOVA relationship between age and the use of VRA

international literature, older farmers were more likely to adopt VRA technology as the most advanced form of PA currently used. The mean age of farmers who use VRA was 44 whilst those who do not was 42.

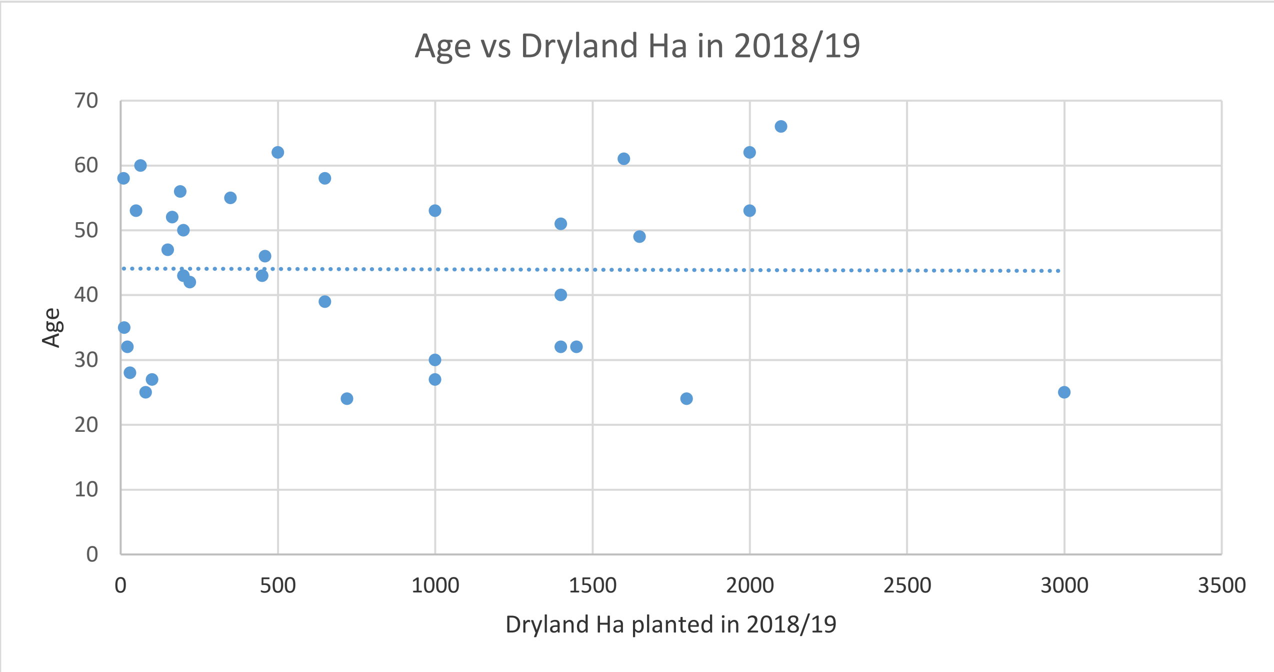

Figure 4.2: Age vs farm size in terms of hectares planted in the 2018/19 season.

There is an assumption that older farmers are operating on a larger scale than younger farmers. To test this, I plotted farm size against age to see if there was any correlation. Taking out NW5M who was an outlier, there was no relationship between age and farm size as illustrated in Figure 4.2 with a flat trend line.

4.1.2 Education

Education was included in this study since it is hypothesised that farmers with a higher education level are more likely to adopt PA technology. Of the 37 respondents, 30% had a matric qualification, 30% had a diploma, 37% had a bachelor’s degree and 3% had a master’s degree as shown in Figure 4.3. From the literature (see for example Jacobs, Van Tol & Du Preez, 2018) one would expect that better-educated farmers are more likely to adopt PA technology. The results obtained in this study is not straight forward in the sense that better-educated farmers were more likely to adopt entry-level PA technology such as auto-steer (see Figure 4.4) but less likely to adopt VRA (see Figure 4.5). Given the results presented one cannot reach a definitive conclusion regarding the correlation between education and PA adoption, hence this will have to be explored further within the logit model.

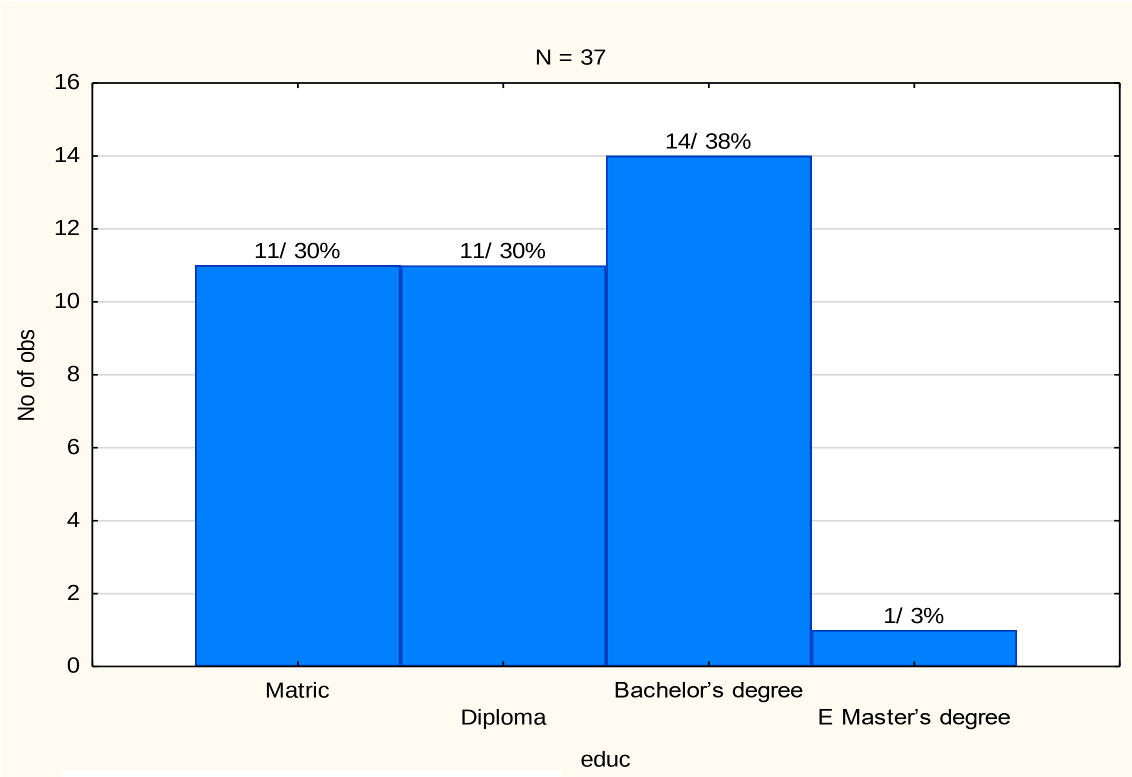

Figure 4.3: Education level of farmers

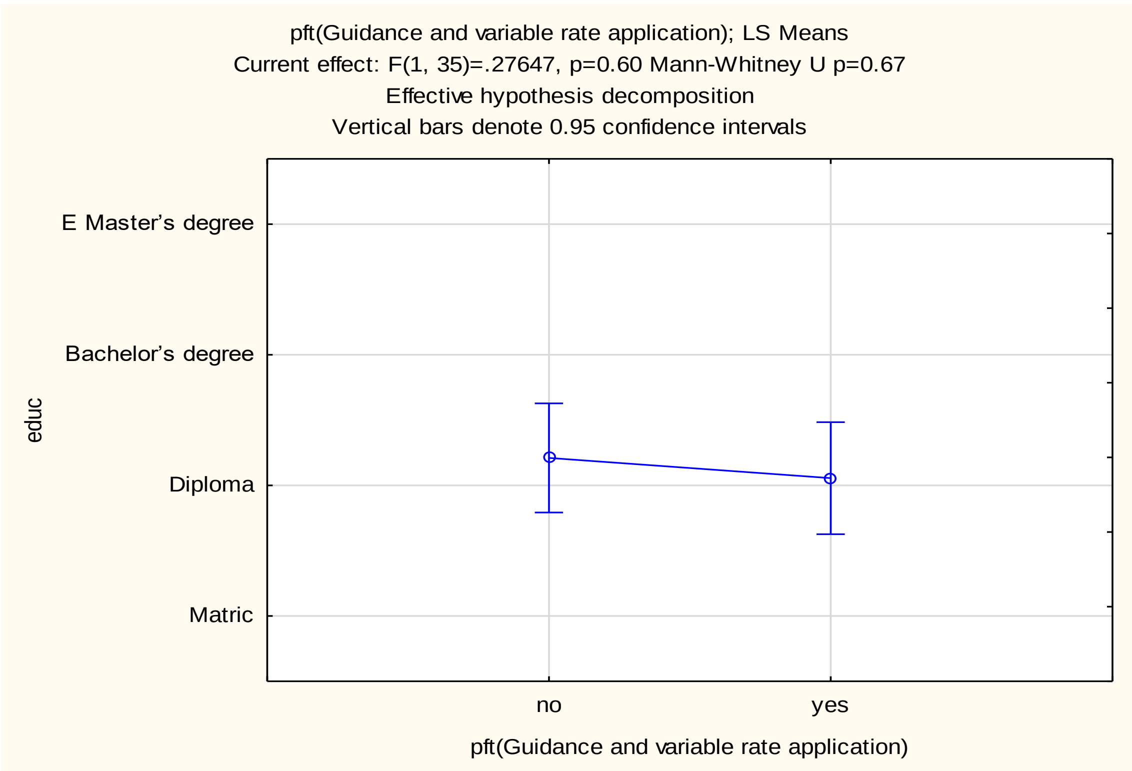

Figure 4.4 ANOVA relationship between Education and adoption of VRA

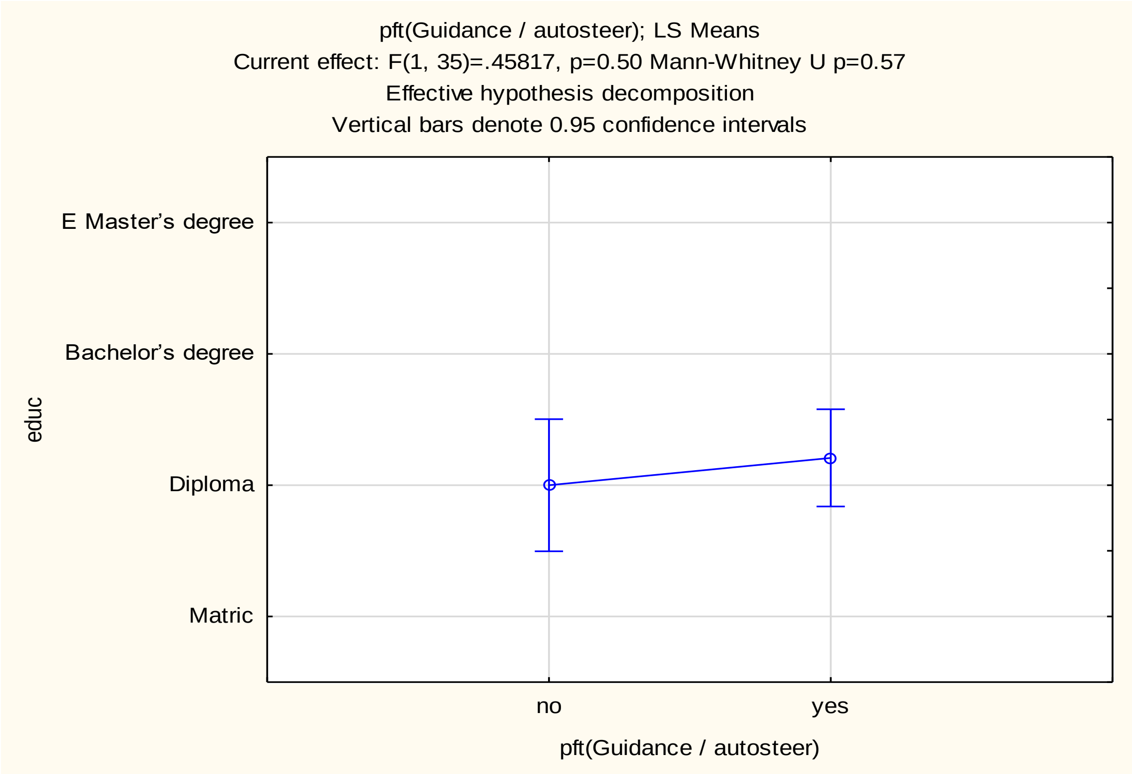

Figure 4.5: ANOVA relationship between Education and autosteer

4.2 Farm properties:

4.2.1 Farm location

This section explores the relationship between the adoption of PA in terms of VRA and the province in which the farmer was located. Out of the five provinces included in this study, only four were included statistically as the only farmer in the Eastern Cape did not implement VRA. Out of the ten observations in the NW, 50% adopted VRA, and in the Free State 67% of the farmers implemented VRA. The results from Mpumalanga were the inverse of the Free State with 33% adopting VRA and 67% of the farmers not implementing VRA. KwaZulu-Natal had a split of 45% in favour of the use of VRA and 55% in favour of non-use. There is very little correlation between farm location on a provincial level and the use or non-use of PA technologies. Figure 4.6 illustrates the adoption levels of VRA within the different provinces.

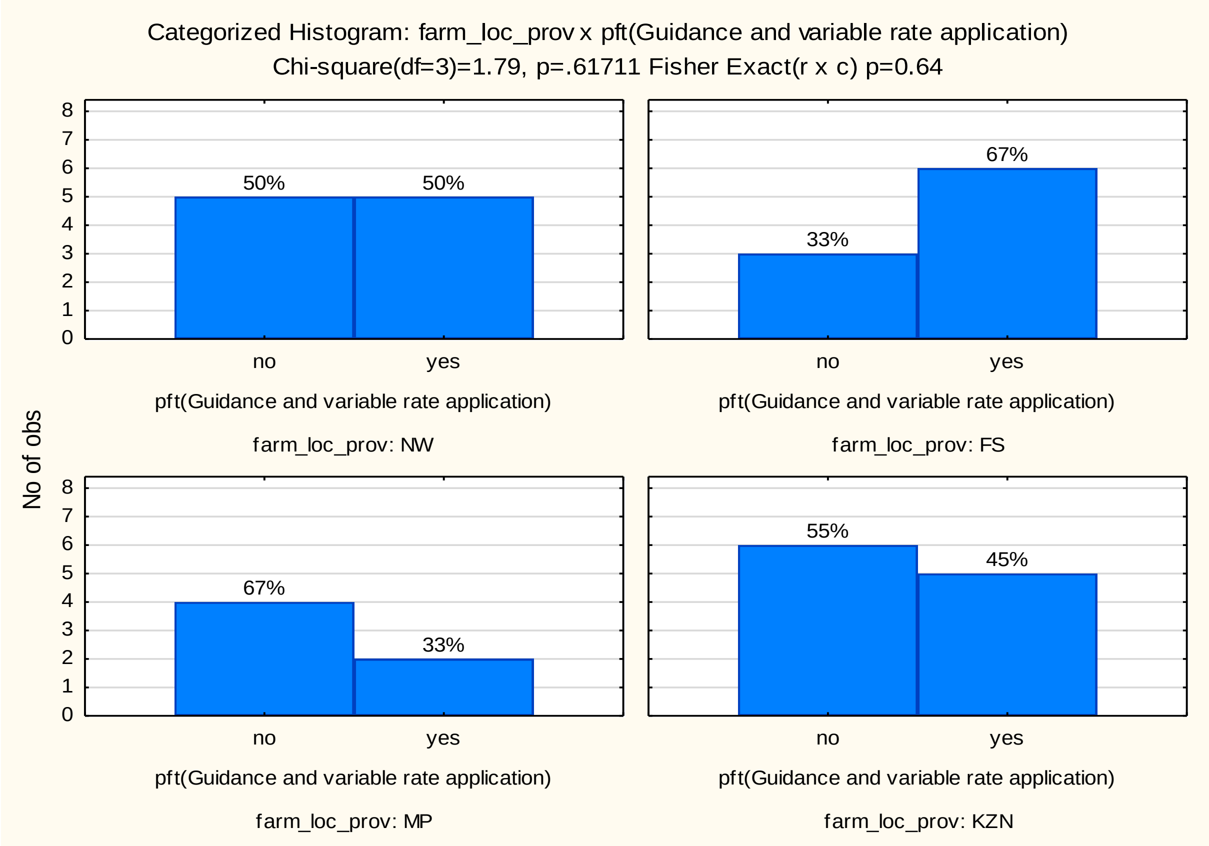

Figure 4.6: Adoption rate of VRA in respective Provinces

4.2.2 Turnover

The relationship between farm turnover and the use of PA is assumed to be strong due to the economies of size effects. Economies of size refer to the cost advantage gained by companies when production becomes efficient. Companies and production systems achieve economies of size by increasing production and lowering costs. This happens because fixed costs are spread over a larger number of goods (Duffy, 2009). Economies of size exist in the PA equation as the fixed cost of purchasing the hardware or paying annual subscriptions can be divided across a larger number of hectares and therefore becomes more feasible for farmers to implement. Jacobs, Van Tol, and Du Preez (2018) study found this to be true in their case study in the Schweizer-Reneke region. The relationship between annual farm turnover and the adoption of PA technology (VRA, section control, and guidance). In Figure 4.7 the relationship can be seen to be positive between the use of section control and annual farm turnover.

The mean turnover for farmers who practise section control is R27.0 million (nineteen observations) while the mean farm turnover for those farmers who do not practise section control is R11.0 million (eighteen observations). The relationships between annual farm turnover and the adoption of auto-steer are similar with a mean farm turnover of R23.6 million for the use of auto-steer and R11.3 million for the non-use of auto-steer. The trend continued for VRA, with the mean annual turnover for the use of VRA being R23.4 million and the non-use being R15.4 million. Figure 4.7 illustrates the relationship between annual farm turnover and the implementation of guidance and section control. The relationship between annual farm turnover and the adoption of PA is positive, which means that farmers with a higher annual farm turnover are more likely to adopt PA technology compared to those farmers with a lower annual farm turnover.

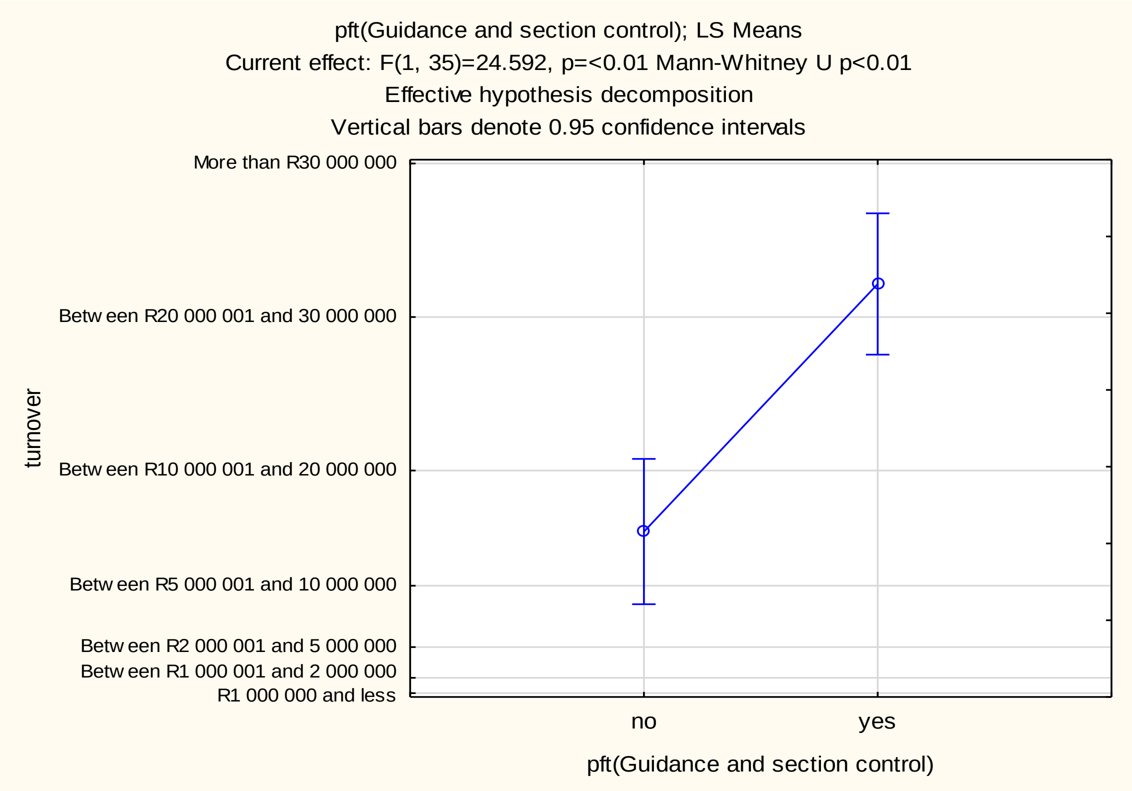

Figure 4.7: Relationship between annual farm turnover and the use of Guidance and section control

4.2.3 Farming Enterprises

The majority of the farmers who completed the survey (94%) were mixed farmers who had some form of animal husbandry in their farming system. While 6% of the farmers were exclusive crop farmers. Beef was the main livestock activity as farmers get the most out of their crop by grazing beef cattle on their maize residues over winter when the carrying capacity of natural grazing becomes low (De Waal & Combrinck, 1990). Figure 4.8 illustrates the dry matter produced per ha per year of natural grazing, this shows the time of the year when nutrition is limited for animals which start in April and starts ending in August. This is the time of the year when farmers are harvesting and have maize stover/stalks for the cattle to graze on.

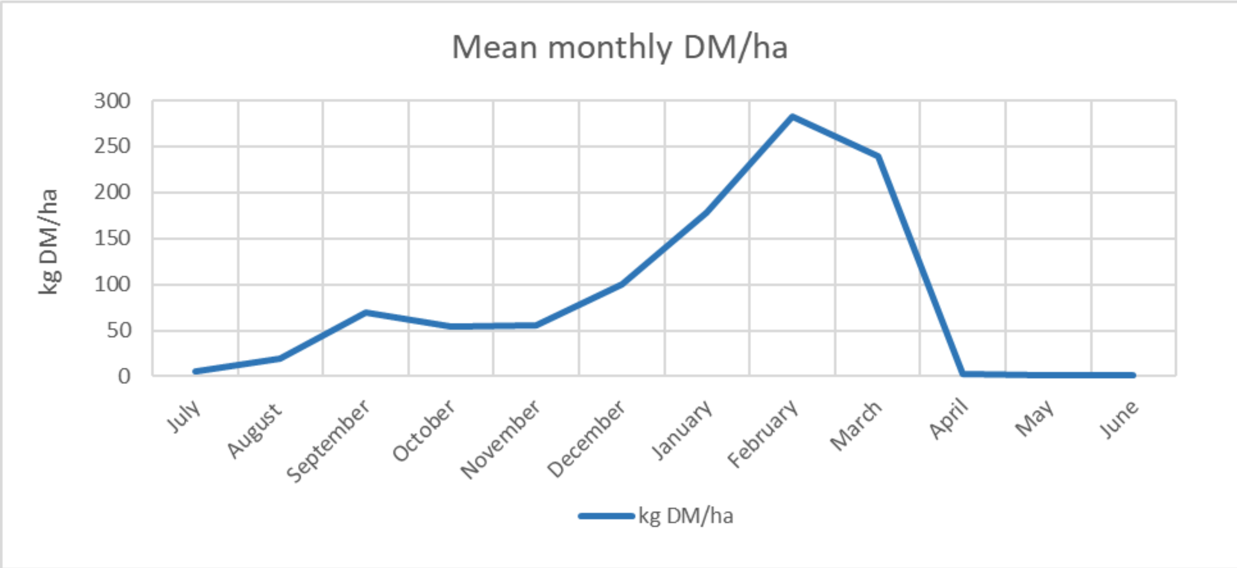

Figure 4.8: Mean monthly dry matter produced off native grazing (veld) in the Free State

Source: De Waal et al., 1990

The remaining farmers participated in more intensive animal production systems such as poultry, pork, feedlots, and dairies where farmers added value to their maize by feeding it to their livestock. These farmers often lower their on-farm maize price which allows them to work with a larger profit margin. The majority of the farmers that participated in the survey were mixed farmers with 89% of those farmers participating in some form of beef production with the next highest contributor to a mixed farming system being dual-purpose sheep with a 16% contribution.

There is a positive relationship between mixed farming practises and the adoption of PA technology. With all else remaining equal, there is a higher chance that a farmer users PA technology if he has a mixed farming enterprise compared to that of an exclusive crop farmer.

4.2.4 Crop rotation

Maize was found to be the dominant crop in the crop rotation systems. Several farmers practised monoculture while farmers in areas with higher average rainfalls planted a winter cover crop. The major crop used in the crop rotation schedule is soybeans followed by sunflowers. Soybeans were more dominant in parts of the country where there is a higher average rainfall (Mpumalanga and the Eastern Free State). The drier western regions (Western Free State and North West) were more inclined to use either sunflower or sorghum in their crop rotation schedule with maize. Cover crops play an important role in conservation agriculture with various potential benefits including reduced compaction, increased water infiltration, and reducing and limiting evaporation while contributing to the soil organic matter (Trytsman, 2018). Cover crops are especially popular in the zero-tillage farmers as a cover crop with numerous different species provides the correct pore spaces in the soil as well as dealing with compaction far deeper than any mechanical implement can reach.

In terms of other field crops planted by maize farmers, soybeans were the most popular which comprised 51%, followed by sunflower at 32%, with sorghum and wheat sharing the remaining 32% with 16% each. Figure 4.9 illustrates the ratio in which other field crops were used.

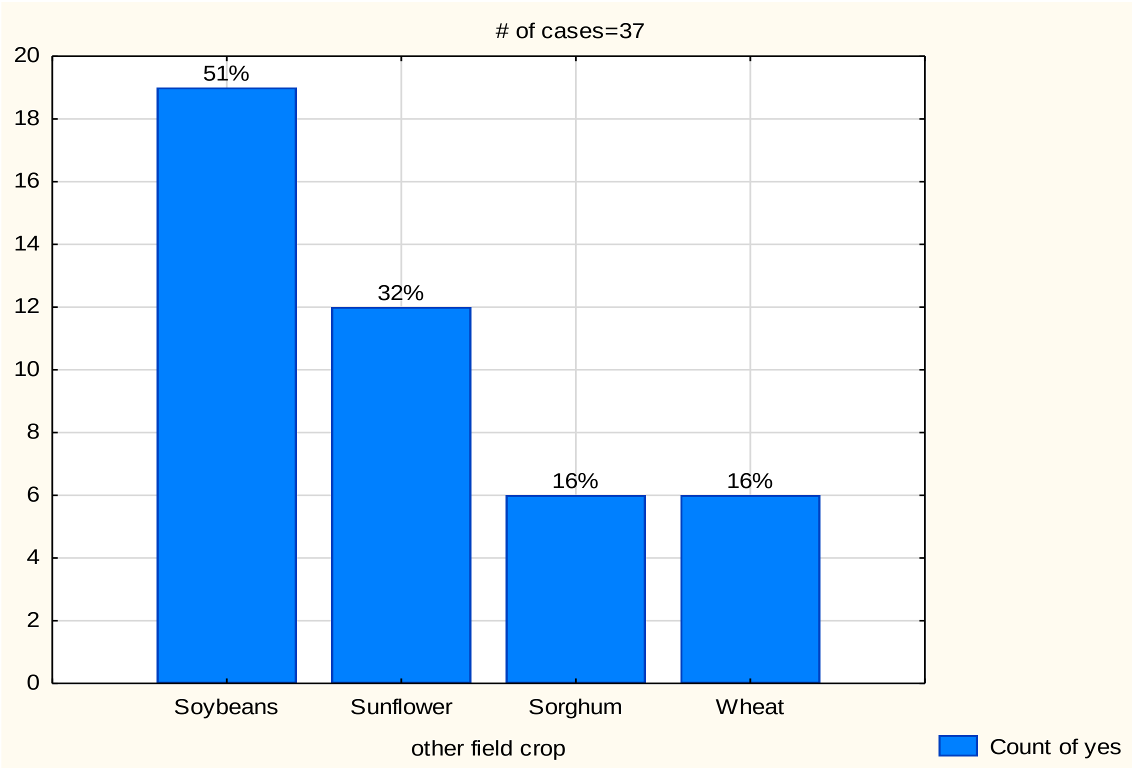

Figure 4.9 Other field crops used in grain production

A total of 76% of the farmers surveyed participated in some form of crop rotation. Of the 76% that partake in crop rotation systems, 82% of them use some form of PA technology. A positive relationship can be seen between the adoption of PA technology and the implementation of crop rotation strategies.

4.2.5 Tillage techniques

There was an even split between the three different planting/tillage techniques across the thirty-seven surveys completed with 30% practising conventional practises, 40% practising conservation/minimum tillage, and 30% practising zero-tillage techniques. Conventional tillage was defined as cultivating the entire soil surface before planting with the use of mechanical means to eliminate weeds. Minimum tillage was defined as less than 20% mechanical disturbance of the soil. The idea behind minimum tillage is to disturb the soil as little as possible with mechanical means while still obtaining a suitable seedbed and neutralise weed competition. Zero tillage was defined as using no mechanical means to prepare the seedbed or deal with weeds, instead the seed is planted straight into the residue from the previous year's crop. Zero-tillage requires a more intensive chemical weed management program relative to systems with greater use of mechanical implements. Figure 4.10 illustrates the accumulative number of hectares planted to each tillage technique in the 2018/19 season. During the 2018/19 season, the thirty-seven farmers planted approximately 35 073 hectares. Even though conservation agriculture comprised 40% of the farmers, in total

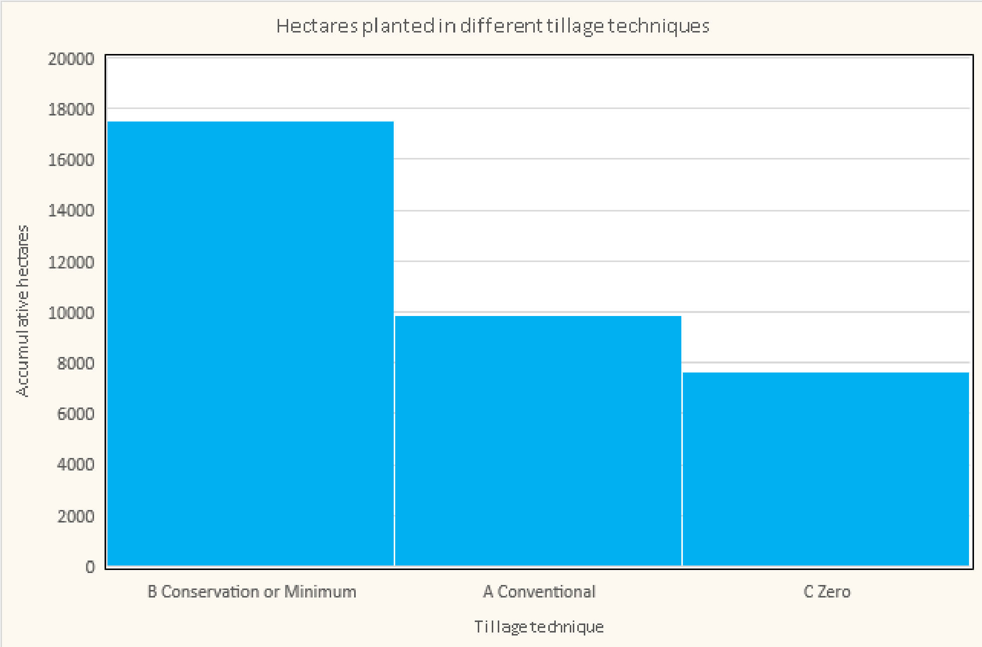

Figure 4.10: The quantity of hectares planted in each tillage technique.

it accounted for 50% of the total area planted. This leads to the assumption that farmers who practise conservation/minimum tillage techniques are larger farmers than those who practise conventional and zero tillage.

4.2.6 Dryland vs irrigation

During my study, I documented the number of hectares planted by farmers for the seasons 2016/17, 2017/18, and 2018/19. Both dryland and irrigation production systems were considered by hectares planted as well as yields obtained during the relevant seasons. The mean hectares planted for dryland started at 880 hectares for the 2016/17 season which climbed to 933 hectares in the 2017/18 season and finally reached 974 hectares in the 2018/19 season. It was estimated that there are 9000 commercial maize producers in South Africa (Department of Agriculture, 2017), in 2017 the total number of hectares planted to the maize was 2 633 685 (SAGIS 2020), this leads to an approximate average of 292 hectares per farmer.

On the irrigation side, the results were inverted relative to the dryland hectares planted with a mean of 200 hectares planted in the 2016/17 season falling slightly to 197 hectares in 2017/18 and then falling further to 180 hectares in the 2018/19 season. There were 36 observations across all three seasons for dryland while there were 10 for irrigation in 2016/17 which grew by 1 each year to reach 12 in the 2018/19 season. The dryland average yields were 6.8 tons per hectare in 2016/17, 6.7 tons per hectare in 2017/18, and 6.3 tons per hectare in 2018/19. This is above South Africa's long term average of 5 tons per hectare (Maluleke, 2019).

The irrigation yields were invariable with 11.6 tons per hectare in the 2016/17 season, 11.8tons per hectare in the 2017/18 season, and 11.9 tons per hectare in the 2018/19 season.

Figure 4.11 illustrates the use or non-use of guidance/auto-steer concerning the number of dryland hectares planted in the 2018/19 season. From Figure 4.11 we can see that there is a strong trend for farmers using PA technology with a greater amount of dryland hectares that are planted. Figure 4.12 illustrates the relationship between irrigation hectares planted and the use of guidance or auto-steer. The relationship and illustration of Figure 4.12 are very similar to that of Figure 4.11. The results illustrate that farmers with a greater number of hectares across both dryland and irrigation production systems are more likely to adopt PA technology. The results from the adoption of the remaining PA technology in section control and VRA showed a mirror image of the relationship between guidance and hectares planted, so they were therefore not included.

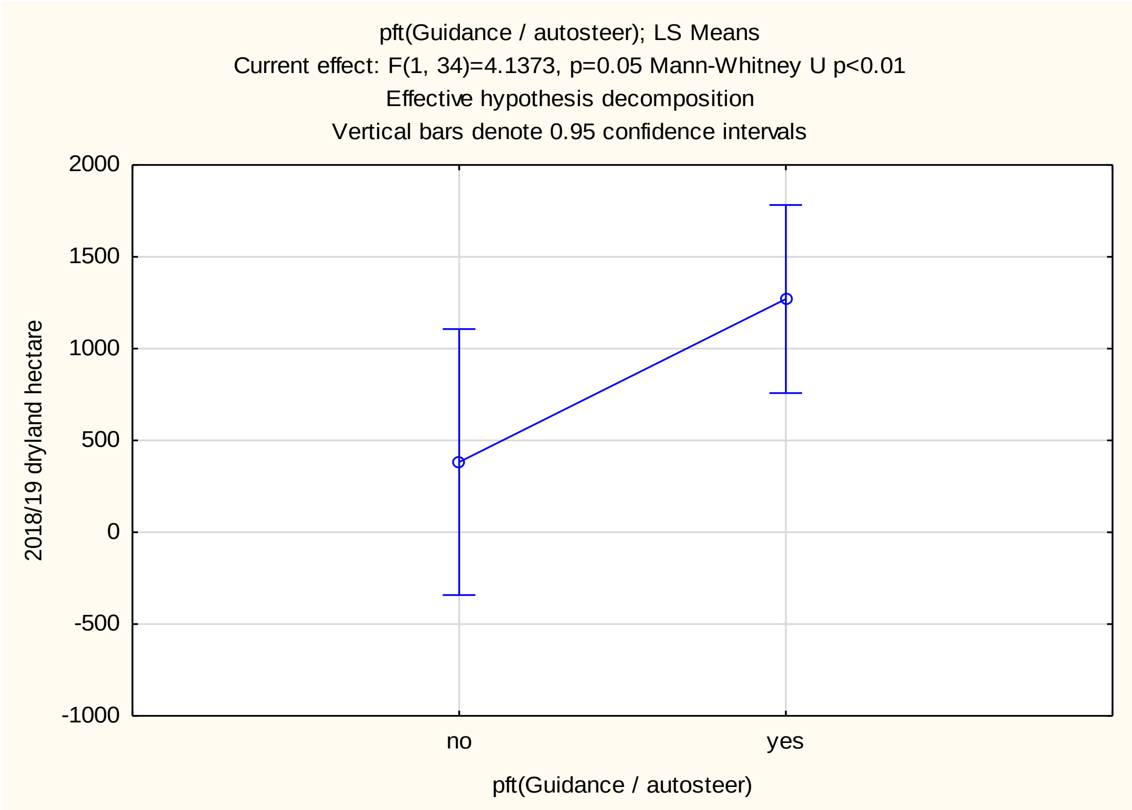

Figure 4.11 Comparison between dryland hectares planted concerning the use of guidance/auto-steer

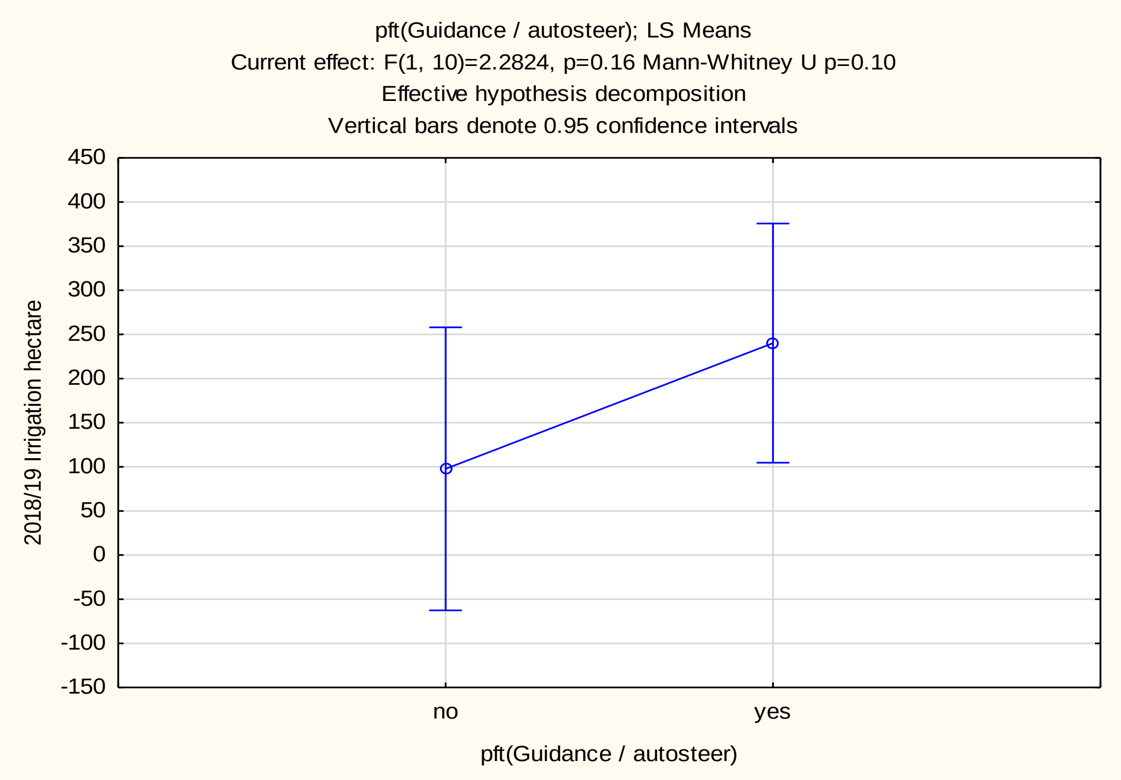

Figure 4.12: Comparison between irrigation hectares planted concerning the use of guidance/auto-steer

4.3 Precision agriculture attributes

4.3.1 PA information sources

There are several sources of information for farmers concerning PA. These sources include machinery suppliers, input suppliers, precision agriculture consultants, extension officers, other farmers, shows or farmers' days, and the internet. In my research I asked who farmers think the most important source of information is on PA, 40% replied precision agriculture consultants followed by 20% for machinery suppliers and 14% for input suppliers. Along with who the farmers thought was the most important source of information I also asked the question of where farmers obtain their PA information.

Figure 4.13 refers to where farmers learnt and acquired information regarding PA technology and information. 41% of the farmers mentioned precision agriculture consultant, of the farmers that use VRA, 50% used a precision agriculture consultant to generate their VRA prescription maps, while 33% indicated that input suppliers generate their VRA prescription maps for them. Input suppliers account for 35% of the information provided to farmers. Other farmers are an important category for learning more about PA technology, this is due to farmers working and dealing with these technologies on a farm and practical level which allows other farmers to give farm level feedback. Machinery suppliers register at 35%, machinery suppliers dealing with farmers are offer the latest technology to help farmers deal with the ever-changing environment. Machinery suppliers such as John Deere provide PA information handling programs in PA software with their operations centre and JDLink systems. Operations centre is used to collect valuable data and information promptly and easily. Operations centre allows you to analyse your data to help you make better decisions or share it with your trusted advisors in the form of input suppliers for chemicals and fertilizers of precision agriculture consultants. JDLink on the other hand allows you to manage your operation in real-time without being in the machine. JDLink provides the potential for you to take your operation to the next level of efficiency and productivity without having to leave your office.

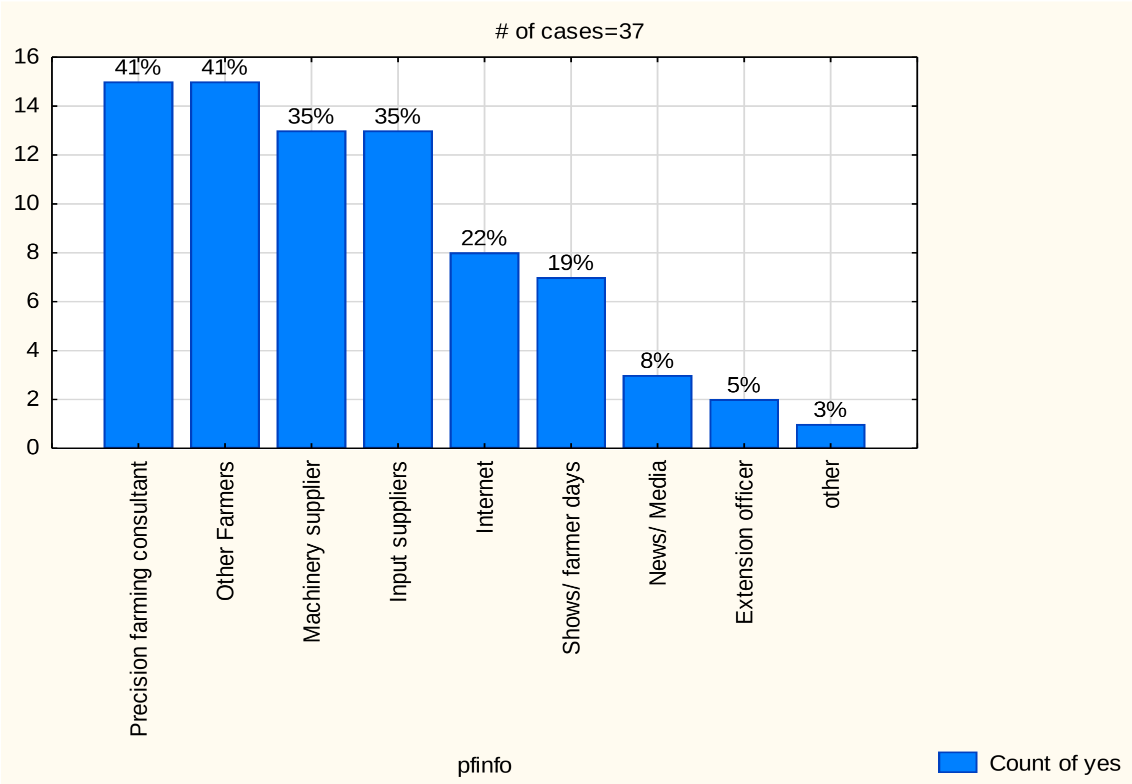

Figure 4.13: Sources of PA information

4.3.2 Guidance systems used.

A total of 49% of farmers in the survey used GPS auto-steer/guidance systems with a paid-for GPS signal. This subscription allows farmers to obtain a higher level of accuracy compared to those farmers using guidance systems with no subscription which encompasses 65% of farmers in this survey. Guidance systems without a subscription can achieve a horizontal pass-to-pass accuracy of +/- 15cm, with no repeatability, an example of a guidance system is the SF1 series from John Deere or the EZ-Guide 250 from Trimble. A paid-for GPS system can achieve a +/- 3cm horizontal pass-to-pass accuracy, this system can also achieve +/- 3cm repeatability within a season, an example is the SF3 series from John Deere (John Deere sub-Saharan Africa, 2020).

For those farmers seeking a higher level of accuracy, RTK base stations or RTX systems are utilised, 24% of the farmers used RTK/RTX GPS systems. Farmers who use a paid-for GPS system have been doing so for predominantly eight years or less. The information from the 24% of farmers that use RTK/RTX systems had the same distribution as that of paid GPS users with a 75th percentile being eight years or fewer. RTK systems can achieve a +/- 2.5cm horizontal pass-to-pass accuracy as well as long-term repeatability of +/- 2.5cm which plays an important role in farmers seeking to adopt control traffic farming operations. Controlled traffic farming incorporates several technologies to confine the traffic of farm machinery to defined tramlines within a cropping field. Controlled traffic farming confines compaction to the defined tramlines while supporting soil structure improvement between tramlines, raising the potential for improved yields along with reducing the overlap of inputs which reduces crop inputs (Kingwell & Fuchsbichler, 2011:513).

A total of 49% of farmers implemented VRA with 14% intending to implement it in the short-term future, while 37% currently do not implement VRA with no intent to use it in the short to medium-term future. Modern-day contractors can provide the optional use of VRA on their machines which allows smaller farmers the benefit of using PA systems without having to outlay large capital amounts for equipment upfront. There was a 51% implementation of section control over the farmers surveyed. With 26% intending to implement it in the short to medium-term future and the remaining 25% not using it. The section control mentioned above is electronic section control whereby the software provided reduces the usage and increases the efficiency of inputs as it cuts off sections when it detects that you have are overlapping.

4.4 Logit model results

A logit model was constructed to identify the farmer attributes that predict the adoption of PA technology. The independent variables included in the logit model were farmer age, education, annual farm turnover, dryland hectares planted, and mixed farming practise or exclusive crop production. Farm location at a provincial level was removed from the section as it was statistically excluded.

The Wald statistic is an interim statistic to test whether the coefficients in the logistic model for each predictor is significant or not. The p-value is derived from the Wald statistic. Guidelines to test for statistical significance would be that $p<0.05$. $P> 0.05$ but close to 0.05 indicate a trend in a certain direction with the sign of the coefficient lending to that specific trend.

P-values of all of the independent variables were statistically insignificant. The independent variable in the area planted for the season 2018/19 showed a trend representing a p-value of 0.09. This indicates a positive relationship between the area planted and the adoption of PA technology. The relationship between the provinces and the use or non-use of VRA was run in the logit model. The p-value for this relationship was 0.82 which is statistically insignificant.

The two variables in my study that contradicted that of both the international and South African literature were age and education. Age although statistically insignificant, had a positive relationship with the adoption of PA technology. With everything else remaining equal, there will be a higher possibility of an older farmer adopting PA technology compared to a younger farmer. The literature indicates that younger farmers were more likely to adopt PA technology. Education has a negative relationship with the adoption of PA technology. This negative relationship demonstrates that there is a higher possibility of farmers with a lower education adopting PA technology compared to those farmers with higher education. This independent variable again contradicting that of the international and South African literature on the relationship between the level of education and the adoption of PA technology.

Mixed farming resulted in a statistically insignificant p-value, however, there was a positive relationship between mixed farming practises and the adoption of PA technology. This positive relationship indicates that with all other things being equal if a farmer has mixed farming practises, there is a higher probability that the farmer adopts PA technology compared to that of an exclusive crop farmer. There is a similar trend with annual farm turnover which also has a positive relationship with PA adoption. This positive relationship with all other things being equal leads to a higher possibility of a farmer with a higher annual farm turnover to adopt PA compared to that of farmers with a lower farm turnover. This is in line with both the international and South African literature as it is expected that farmers with a greater annual farm turnover will more likely adopt PA technologies compared to farmers with a lower annual farm turnover.

Table 4.1 : LOGIT model results

Variable	Estimate	Standard Error	Wald Stat.	p
Intercept	-11.978	1087.939	0.0001	0.99
Age	0.038	0.038	1.0187	0.31
Education	-0.012	0.578	0.0005	0.98
Turnover (logged)	0.773	1.29	0.360	0.54
Dryland hectare planted (Winsorised)	0.002	0.001	2.746	0.09
Mixed farmer	0.161	1.558	0.011	0.92

Chapter 5: Farm-level barriers to VRA

5.1 Farm-level barriers to VRA

The first section of the survey with regards to farm level barriers tested the reasons on the side of VRA non-use. These questions were answered on a disagree/agree platform with 5 different options ranging from strongly disagrees to strongly agree with a neutral option in the middle. I originally did not intend to provide a neutral option that would force a farmer to lean towards a certain direction, however, when conducting my pilot studies, some farmers had no experience or knowledge about a specific statement, and the neutral option was then required. The questions regarding the non-use of VRA systems were only answered by those farmers that are currently not using VRA technology in their farming enterprise.

The first statement with regards to VRA non-use states "VRA will not / does not help me to improve on my current practices since I manage my farm on a per-field basis". This statement focuses on the smaller farmers who have fields that they can manage on a per-field basis without a large range of soil potential within one land. 56% disagree with this statement and 11% disagree strongly which indicates that 67% of the farmers who do not implement VRA believe that it will help them in terms of improving their current management practises. Furthermore, 17% answered neutral and the remaining 17% agreed with the statement. This indicates 17% of farmers believe that they are managing their farming system in a way that could not be improved further by using VRA.

The second statement for the non-use of VRA is "It is too expensive to have VRA prescription maps generated". This statement is purely an economic question with regards to the generation of VRA maps. 39% of the farmers disagreed with this statement yet again, illustrating that several farmers that do not implement VRA do not think it is too expensive in terms of their return on investment, 22% were neutral as they did not have any experience or knowledge of the costs involved in generating VRA maps. 22% and 17% of the respondents stated that they agree or agree strongly with this statement. The next statement continued along with the topic of economic barriers as it refers to the cost of the hardware used in VRA, "It is too expensive to purchase the necessary machinery and hardware to execute VRA maps". Similar to statement 2, there are split answers with 33% disagreeing with the statement, 11% being neutral and 28% for both agree and agree strongly. What can be seen as the expense is often expressed as a capital-intensive system whereas farmers should depreciate that cost over their annual hectares planted as well as over five or more years.

Statement 4 with regards to the non-use of VRA focuses on whether farmers trust the technology and the dependability of the technology, "The hardware used to execute VRA is not dependable and thus causes in field delays". There is a strong consensus that this is not the case with no one agreeing with this statement, 11% being neutral, 6% disagreeing strongly and a majority of 83% disagreeing with this statement. This result shows that farmers trust the process and believe that it will not cause in-field delays and be dependable. Statement 5 explored whether farmers have previously used VRA but for some reason have stopped implementing it in their production system, "I've used VRA in the past but did not see the benefits thereof?". The data received from statement 5 was similar to that of question 4 with no farmers agreeing with this statement, 22% of the farmers were neutral, 56% disagreeing and 22% disagreeing strongly with this statement. From the sample of 37 farmers, not one farmer that has started using VRA has stopped using it in his system for any reason. This suggests that once farmers implement VRA they see clear benefits and moves forward with it.

Statement 6 focused on the computer literacy of machine operators: "My operators are not computer literate and thus cannot execute VRA". This created a symmetrical split with 39% on the agree and disagree side, respectively, and 22% being neutral. Some of the farmers operate their machinery themselves and therefore do not view computer literacy as a barrier to the adoption of VRA, other farmers that have not yet used VRA intend on sending drivers on training programs. However, 39% of the farmers believe that their operators cannot operate PA with VRA in mind. Note that this question did not imply that farmworkers were responsible for the generation of a prescription map but only sought to establish challenges posed by machine operators to the implementation of VRA.

Statement 7 in terms of VRA non-use was focused on the ability of the farmer to take the prescription maps from the computer in a shapefile and transfer them into the tractor, combine or sprayer where the said maps can be implemented, "I struggle to get the prescriptions (maps) on the tractor". Many of the farmers had little to no experience or knowledge about this as evidenced by the fact that 78% of the responses were neutral while the remaining 23% of responses disagreed.

Statement 8 continued along with the data management vein, this time focussing on the assistance received with generating the VRA prescription maps. "I do not have a good representative to help me write and implement the necessary maps". The results from this statement were similar to that of the previous statement with not much knowledge about this system, 56% replied neutrally with 34% disagreeing. The difference between statement 8 and statement 7 in terms of results is that 11% of responses agreed with this statement, in statement 8 which indicates that some farmers do view this as a farm level barrier, be it a minor percentage. Of the farmers that implemented VRA, 50% used a precision agriculture consultant to prescribe VRA maps, 33% made use of input suppliers and 17% generated their prescription maps. This is illustrated in figure 5.1.

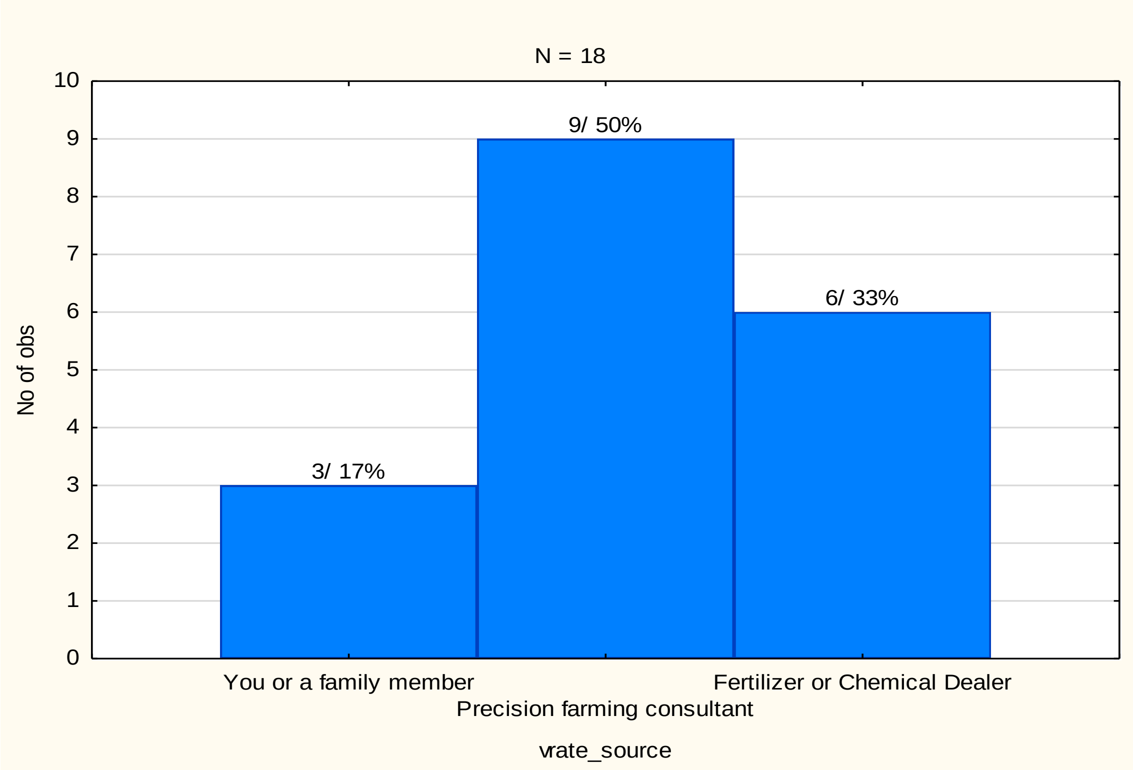

Figure 5.1: Generation of VRA prescription maps

5.2 Farm-level barriers to section control

The next sector focused on the non-use of section control, this again was only answered by farmers that currently do not use section control in their farming enterprise. The section control non-use figures were illustrated on a graph with yes and no on the x-axis. Yes, indicates that the farmer users VRA and not section control and no indicates that a farmer uses neither section control nor VRA. The first statement asked farmers whether they have machinery with the capability to carry out section control. “I do not own the necessary equipment to do section control but would use it if I had it”. 70% of responses agreed with the statement, 10% were neutral and 20% disagreed. This implies that 20% of the farmers would not use the capabilities of section control equipment even if it were available to them. This shows that the economic implications do not have a significant impact on the non-use of section control and that there are other barriers to entry. Figure 5.2 illustrates the responses concerning statement 1 of the farm level barriers to section control.

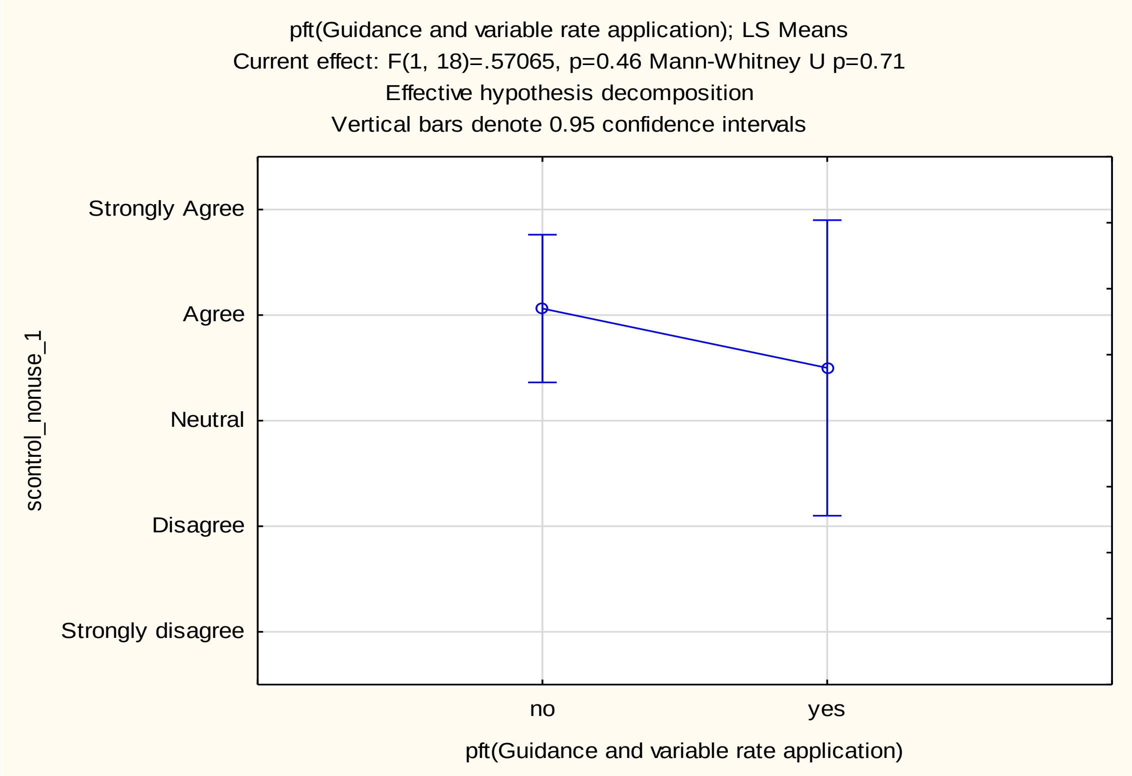

Figure 5.2: Section control non-use 1 statement responses

Statement 2 regarding the non-use of section control enquired whether farmers do not implement section control because it is not suitable for the scale of their farming enterprise. “It is not necessary for the scale at which I farm at”. Statement 2 had mixed results with 47% disagreeing, 43% agreeing and the remaining 11% being neutral. Figure 5.3 illustrates the responses from statement 2. From figure 5.3 we can deduce that farmers that adopt VRA have agreed slightly more to this response than those farmers who do not use VRA.

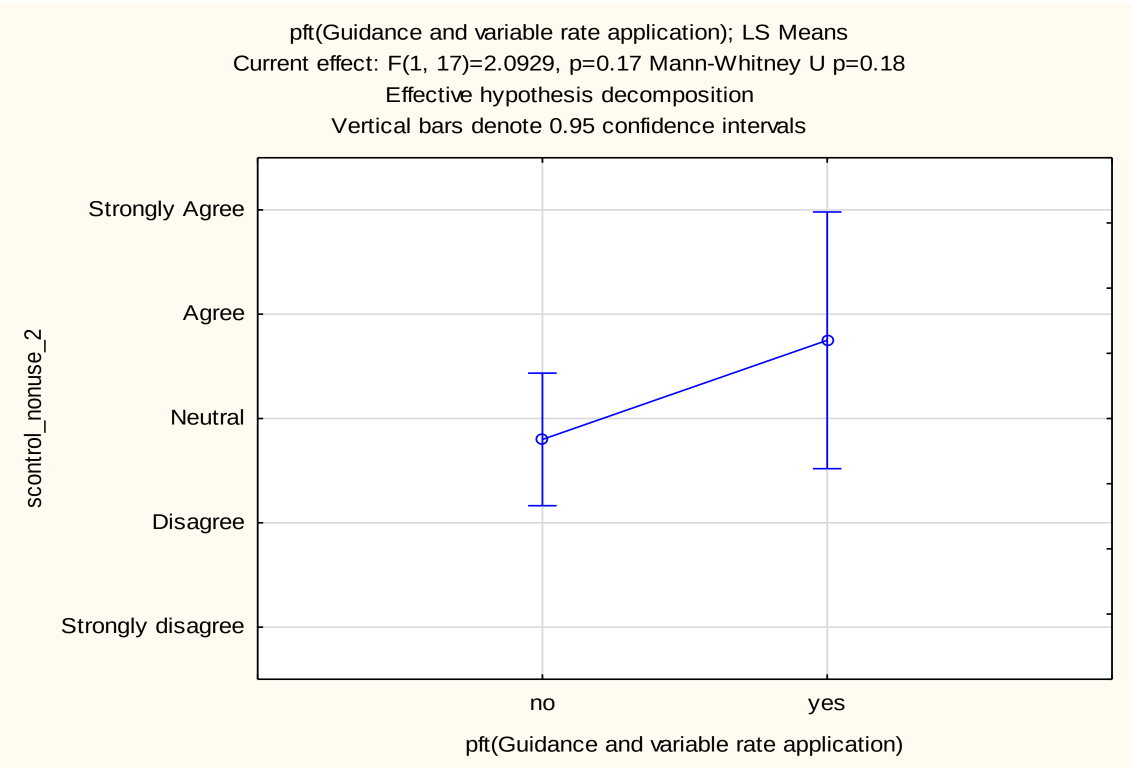

Figure 5.3: Section control non-use statement 2 responses

The responses from farmers that use neither section control nor VRA is neutral, which indicates that farmers have not received much information regarding section control and therefore are indecisive in terms of this statement.

The capital-output used to acquire technologies such as section control is often referred to as one of the main farm level barriers to adoption. Statement 3 focused on this aspect. "Section control equipment is unaffordable". 47% agreed with the statement, 32% of the responses were neutral while 21% disagreed. The 21% of responses that disagreed are in line with the 20% of farmers that answered statement 1 of section control that would not use section control equipment even if they owned the necessary machinery. Figure 5.4 indicates that again, those farmers that do not use VRA have poor knowledge of section control and therefore their answers range around the neutral mark. Whereas the farmers that implement VRA have better knowledge and can therefore answer more towards a specific marker, in this case agreeing on the agree side.

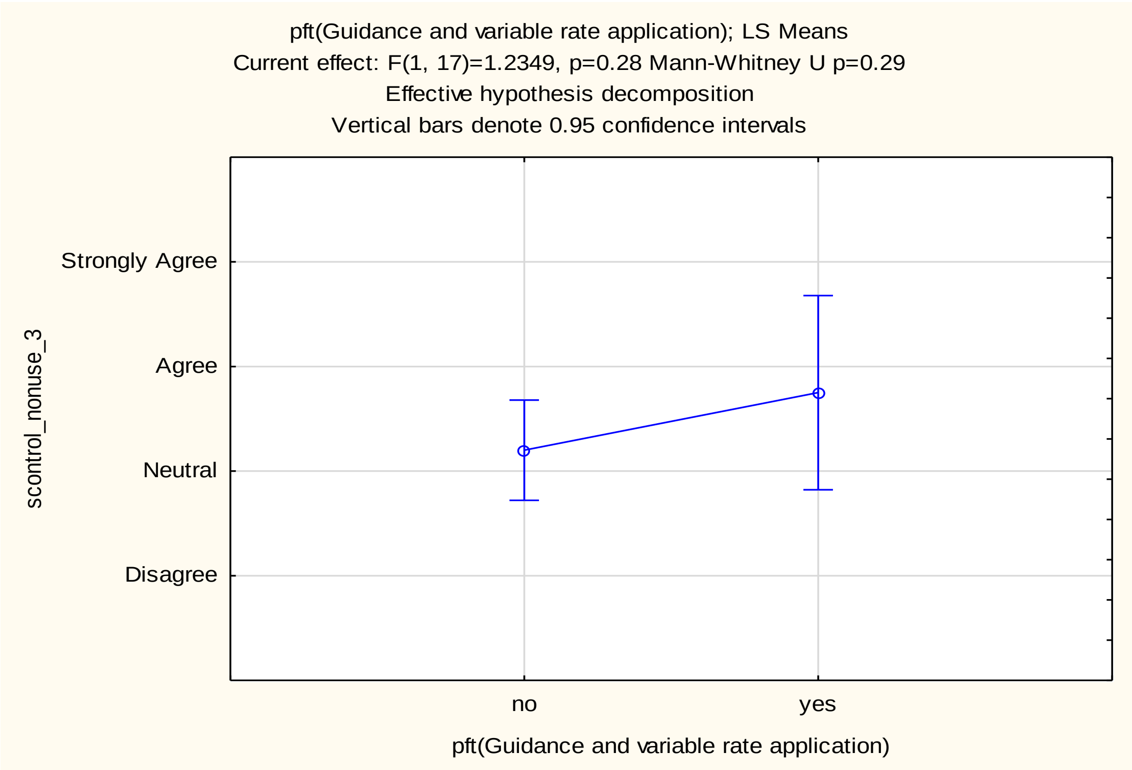

Figure 5.4 : Section control non-use statement 3 responses

Statement 4 regarding the non-use of section control looked at what the farmers believe in terms of technological capability and whether they trust it or not. This statement is along the same lines as statement 4 in the non-use of VRA which asks farmers whether they think VRA will not be dependable and cause field delays. "Section control is less accurate than advertised" with regards to section control non-use, 25% strongly disagreeing, 47% disagreeing and 26% being neutral. This figure is similar to that of statement 4 in the VRA non-use sector with not one respondent agreeing with the statement, this indicates that farmers are not implementing section control because they think the technology is less accurate than advertised and could cause infield delays. Figure 5.5 illustrates the responses from farmers to statement 4 in terms of section control non-use sector.

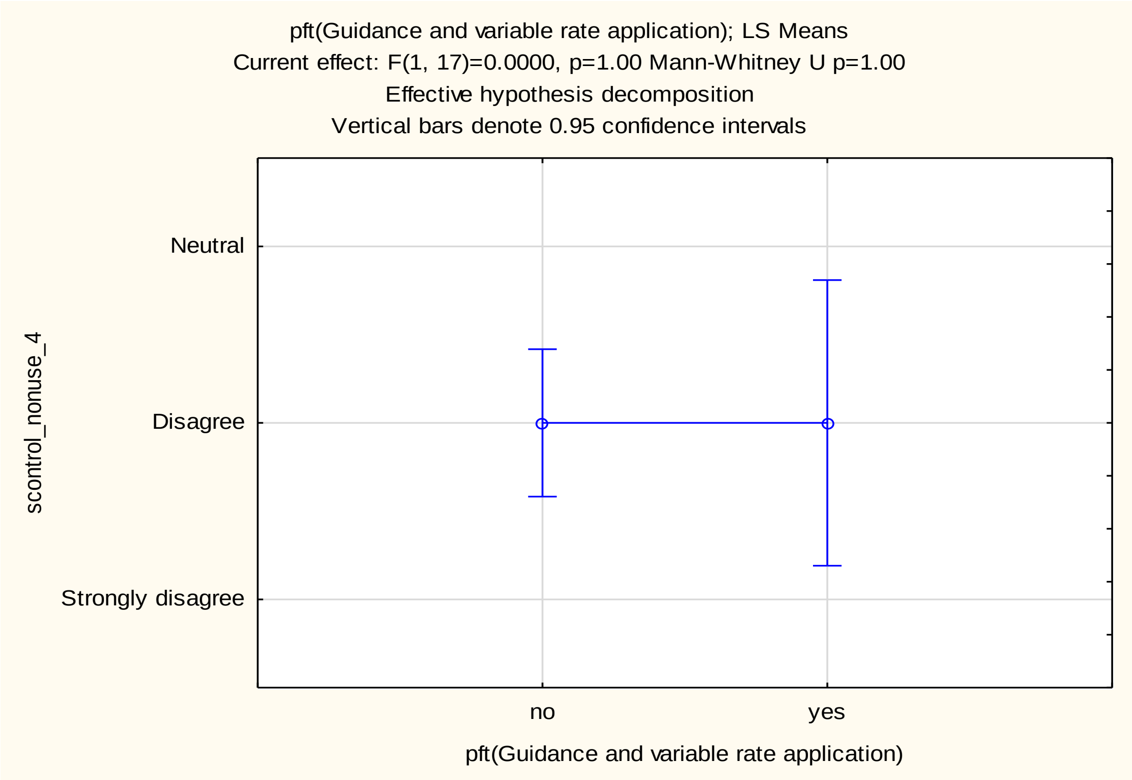

Figure 5.5:Section control non-use statement 4 responses

Statement 5 in terms of the non-use of section control looked at what the future holds in terms of obtaining section control equipment in the next replacement cycle. “I would add section control in my next machine replacement cycle”. From this, 68% of responses agreed that they will look at including section control technology in their next replacement cycle, 16% stayed neutral and 16% disagreed with the statement. With other variables aside, farmers that do not use section control will look at upgrading their machinery to these technology systems in their next machinery replacement cycle. Figure 5.6 illustrates the responses from farmers in relation to the statement regarding implementing section control equipment in their next machinery replacement cycle.

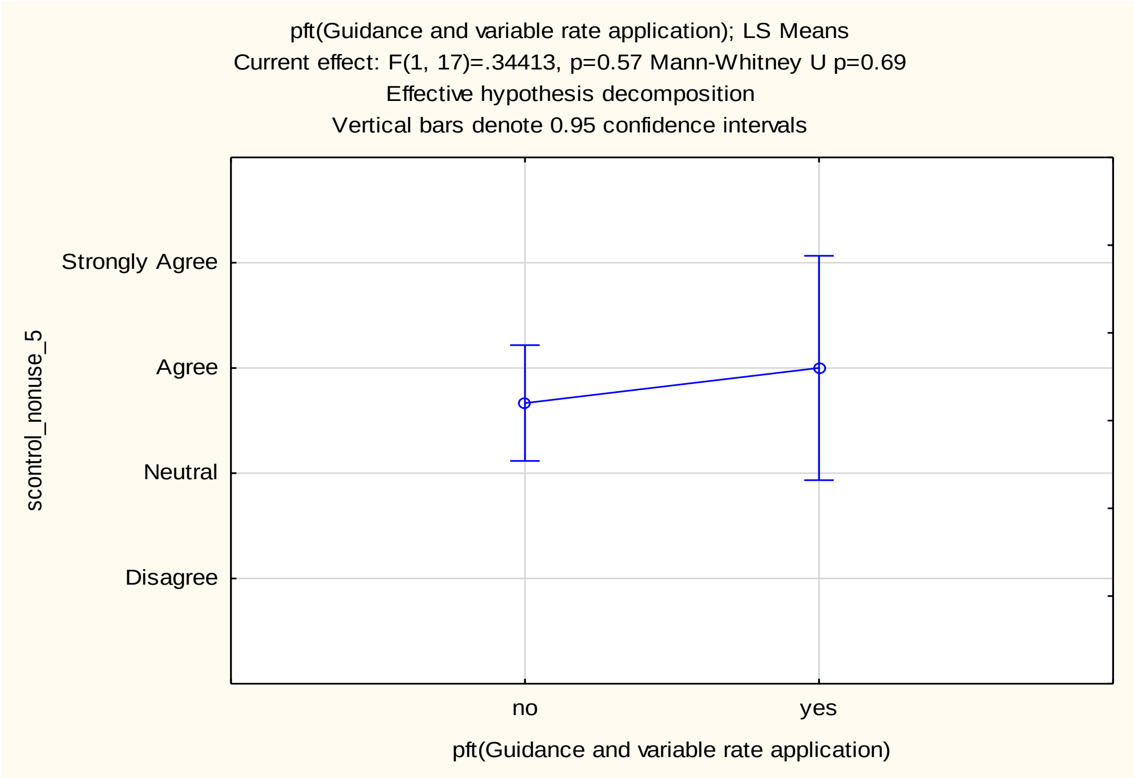

Figure 5.6 : Section control non-use statement 5 responses

Chapter 6: Perceived benefits of using PA technology.

6.1 Perceived benefits

Once I identified the farm level barriers, a list of statements relating to the perceived benefits associated with using PA (Guidance, section control, and VRA) was compiled. This sector was only answered by farmers that use PA technology. The first statement addressed the possible yield benefit from using PA technology, "Using these technologies improves yield". No respondents disagreed with this statement with 15% being neutral, 48% agreeing, and 37% strongly agreeing. Going further into yield increase from using PA technologies, 29% could not quantify the yield increase. However, 21% of respondents stated it was between 3% and 6%, 14% stated that the yield increase was between 6% and 10%, 25% stated that their yield increase was between 10% and 14%, and 11% of respondents stated that the yield increase from using PA technologies was between 14% and 20%. The histogram relating to these responses is illustrated in Figure 6.2. Figure 6.1 illustrates the responses from statement 1 in terms of an ANOVA table, the "no" on the x-axis refers to farmers using PA in the form of guidance and section control while the "yes" refers to farmers that use VRA. We can see the most popular answers were on the agree side. Indicating that those farmers that use some form of PA believe it will improve yield.

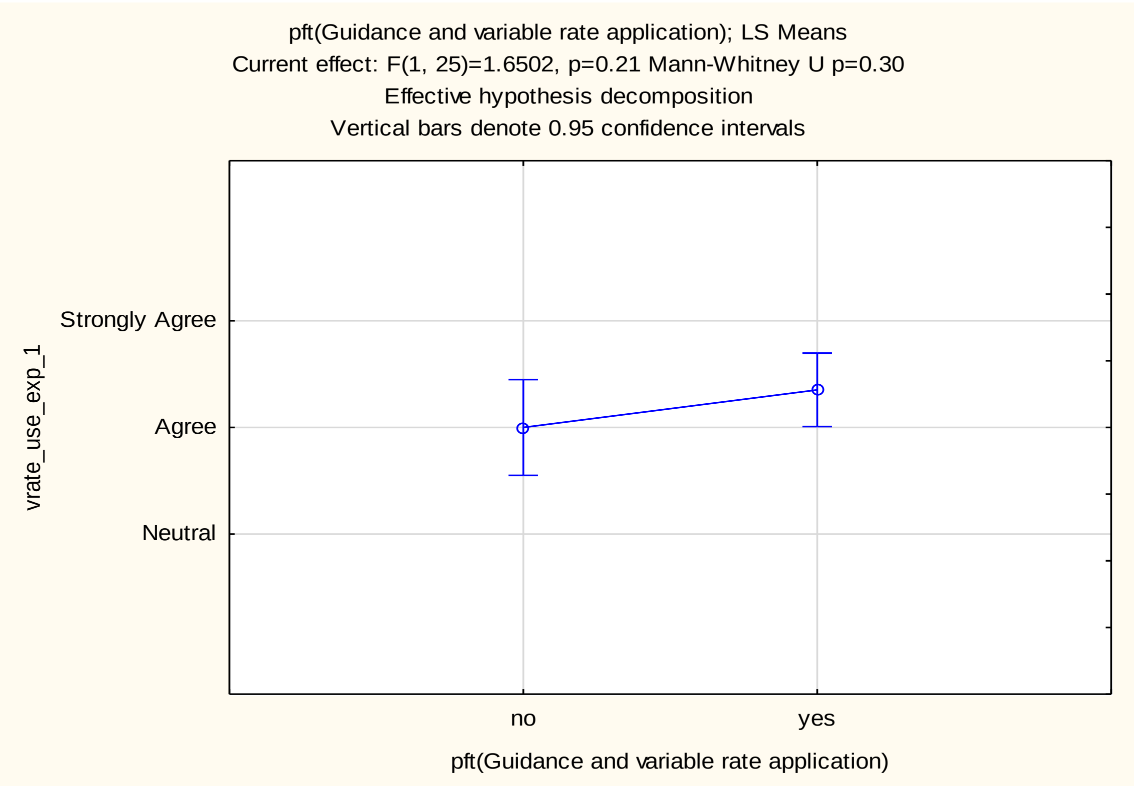

Figure 6.1: Perceived PA benefits statement 1 responses

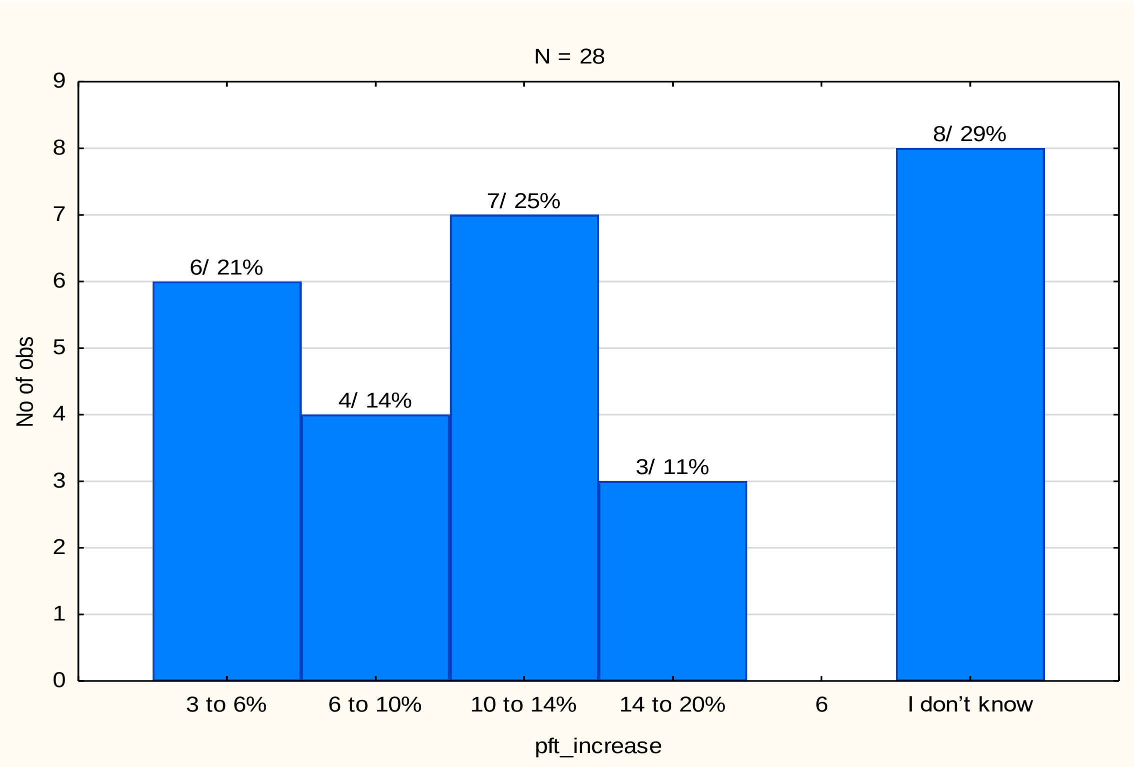

Figure 6.2 : PA technologies increasing yields

The second statement with regards to perceived benefits focused on the yield variability within a field. "Using these technologies decreases yield variability", this statement had split results with 30% disagreeing, 4% being neutral and 66% agreeing. The focus of VRA in terms of in-field variability can be viewed from two aspects, the first by providing more nutrients to the high potential soils to get the most from your capital

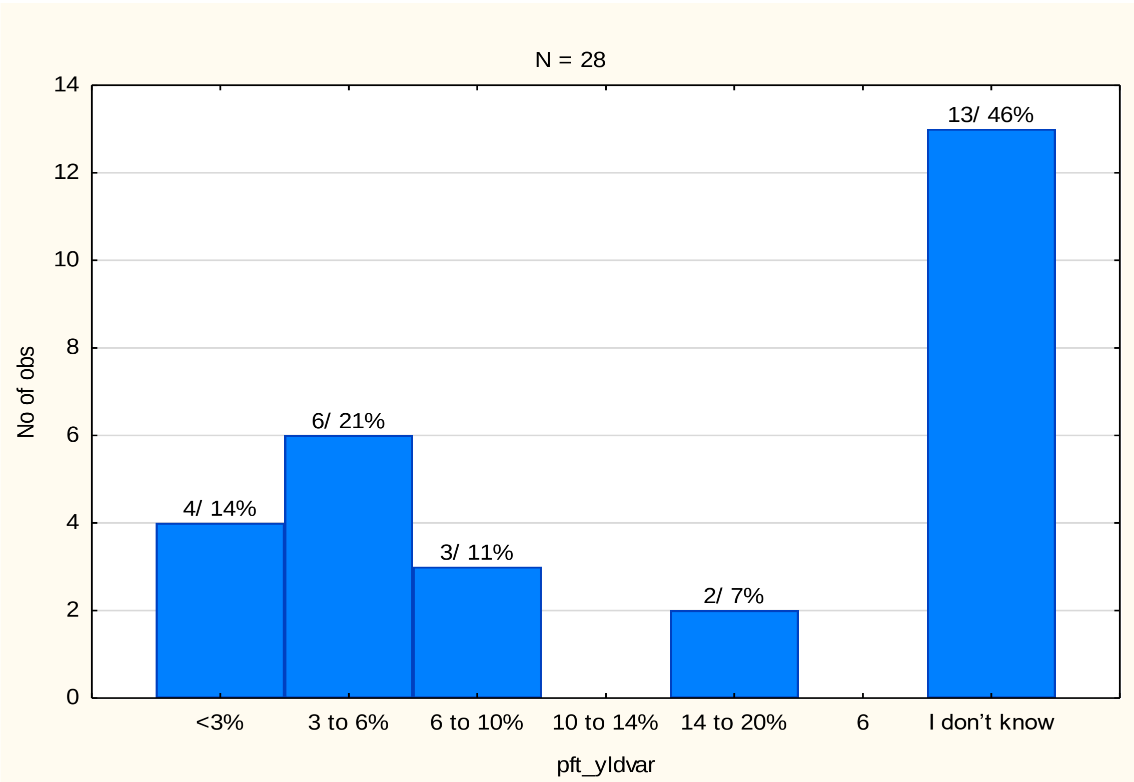

Figure 6.3: PA technologies decreased yield variability

investment, while the second aspect looked at improving the poorer soils through the application of lime and other inputs to increase the potential of those poorer areas. This will decrease yield variability. Figure 6.3 illustrates the responses from farmers regarding the decrease in in-field variability due to the adoption of PA technologies.

Fuel is becoming scarcer, while the price continues inflating. This has made farmers increasingly more aware of their fuel use. There is also an environmental aspect to be looked at in this sector as farmers grow progressively concerned about the environment. The third statement in the benefits to using PA focused on fuel consumption, “These technologies save fuel”. There was a strong response in agreeing with this statement as 59% agreed and 19% agreed strongly, this resulted in 78% of farmers in the study agreeing with this statement, while 15% disagreed. Figure 6.4 illustrates the farmer’s responses in terms of fuel savings from PA technology.

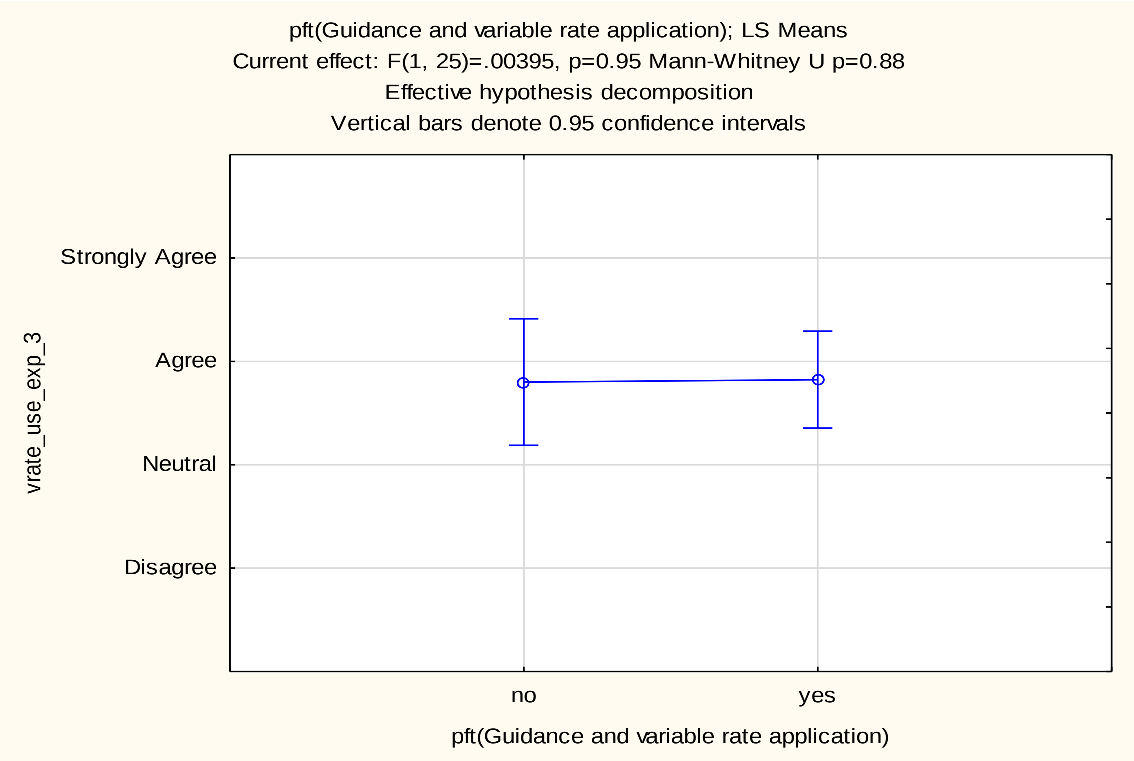

Figure 6.4: Perceived PA benefits statement 3 responses

Along with the increase in fuel prices, the increase in the price of other inputs has also been evident. Farmers are seeking to use their inputs as efficiently as possible. Statement 4 looked at the use of inputs such as fertilizer and seed. “Using these technologies saves seed and fertiliser”. Similar to the results from the statement relating to fuel consumption, 63% agreed with the statement and 19% strongly agreed. This comprises 82% of farmers agreeing with this statement. 7% of the responses were neutral while 11%

disagreed. Figure 6.5 illustrates the responses to statement 4 in terms of the perceived benefits of using PA technologies to economize on seed and fertilizer.

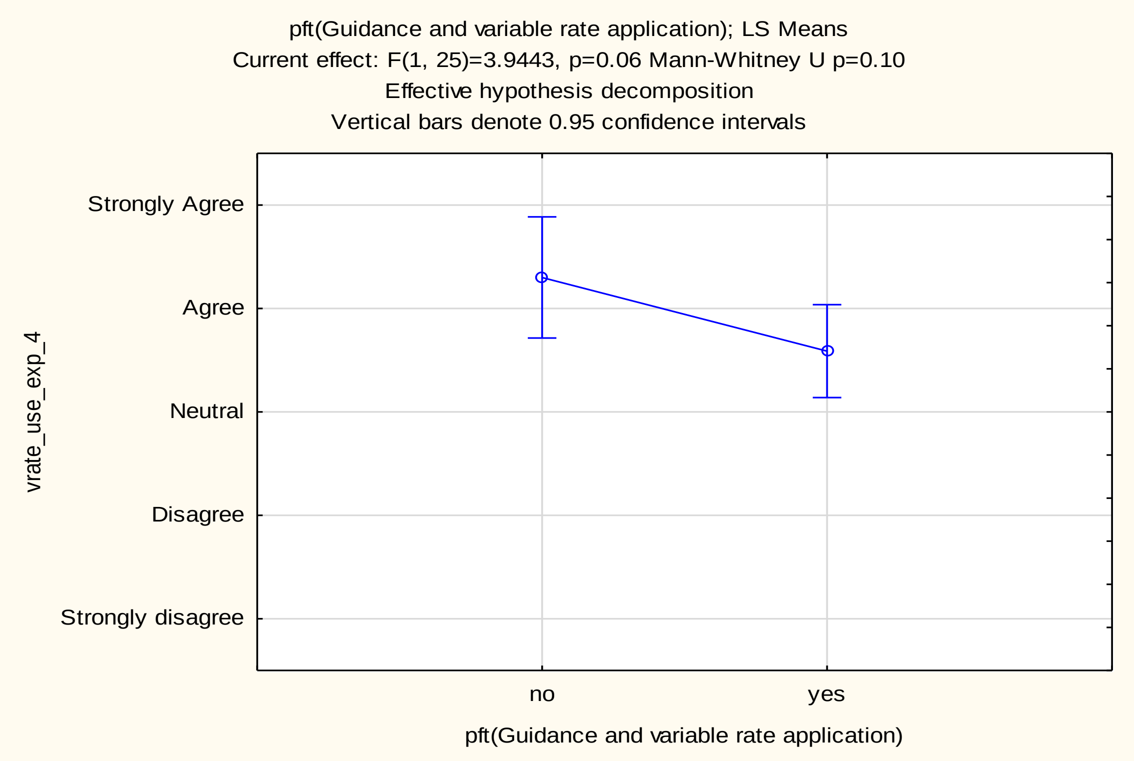

Figure 6.5 : Perceived PA benefits statement 4 responses

South African maize farmers are under pressure with a significant variance in rainfall over the past decade due to climate change (Nell et al., 2006). These PA technologies should allow farmers to get more done in a day by PA systems travelling at greater speeds while maintaining a high degree of accuracy. Statement 5 in terms of the perceived benefits of PA looked at the possible in-field speed and productivity. "Using these technologies improves in-field speed which results in greater productivity", this statement was strongly one-sided with 86% of farmers agreeing with this statement, 7% neutral, and 7% disagreeing. Figure 6.6 illustrates the responses from the perceived benefits from PA. Once again there was a strong consensus that PA saves time while resulting in greater in-field productivity. This is vital for when farmers need to either plant or harvest before it rains or before a certain date.

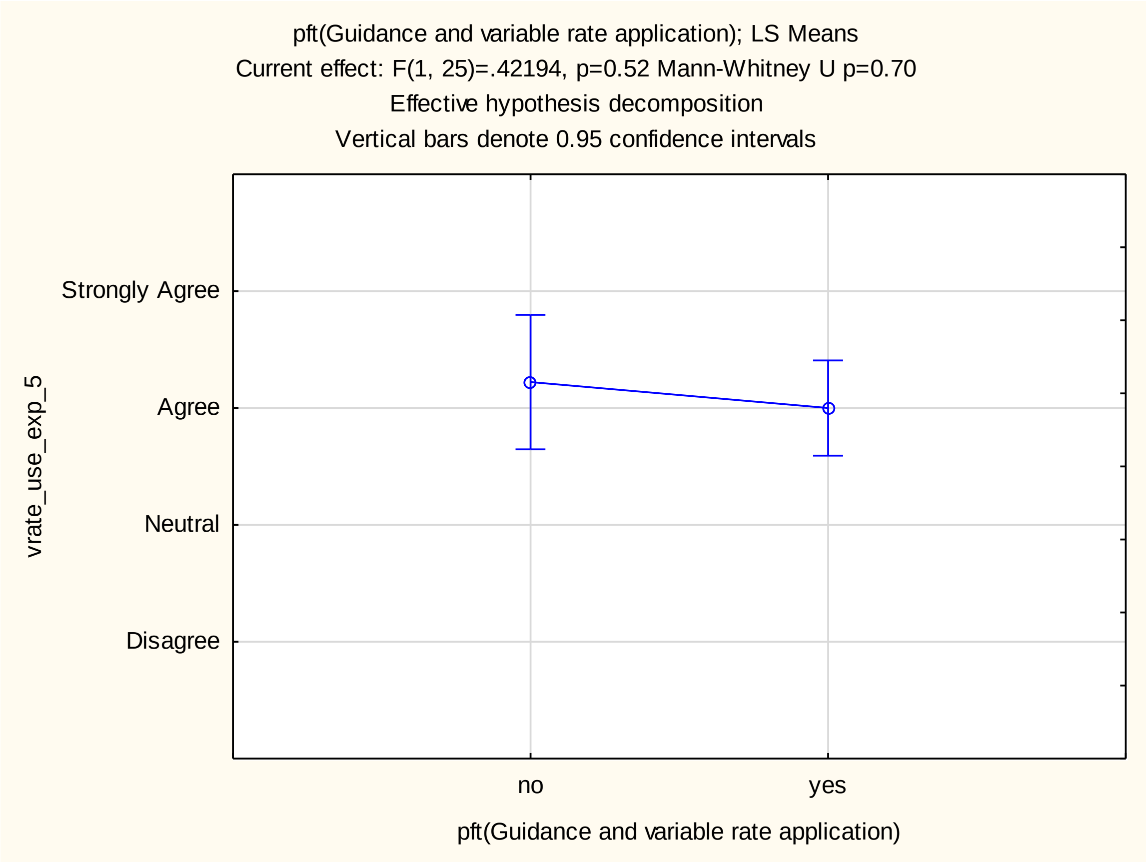

Figure 6.6 : Perceived PA benefits statement 5 responses

The final question is concerning Statement 5. Statement 6 looked at the benefits for the operator of the machinery. What effect does the use of PA have on the operator? "Using these technologies helps a single driver to get more done through reduced fatigue". This statement was majorly one-sided with 78% of farmers agreeing with this statement, 15% being neutral and again 7% disagreeing. The results from statement 6 were similar to that of statement 5. A strong consensus revolving around agreeing indicates that PA technology not only allows the machine to be more efficient but also allows the driver to be more productive. This may occur in the form of monitoring the planter instead of focusing on driving on the planter marker or focus on grain yields, combine settings, grain quality, and moisture when harvesting instead of driving straight.

One of the points that Doerge (2005) stated that turned out to be interesting was that *"Growers may expect higher and more consistent grain quality*" (Doerge, 2005: 24). I, therefore, included a question in my survey regarding the possible improved quality of grain using PA technology. Higher grain quality can lead to a higher percentage of maize being graded as a first grade which obtains a higher price compared to that of second, third, and feed grade maize. This question was answered in a somewhat mixed fashion with 46% stating that they had observed improved maize quality, 25% stating that they had not observed an improved maize quality and the remaining 29% stated that they are not sure. Figure 6.7 illustrates the answers provided by farmers regarding improved maize quality.

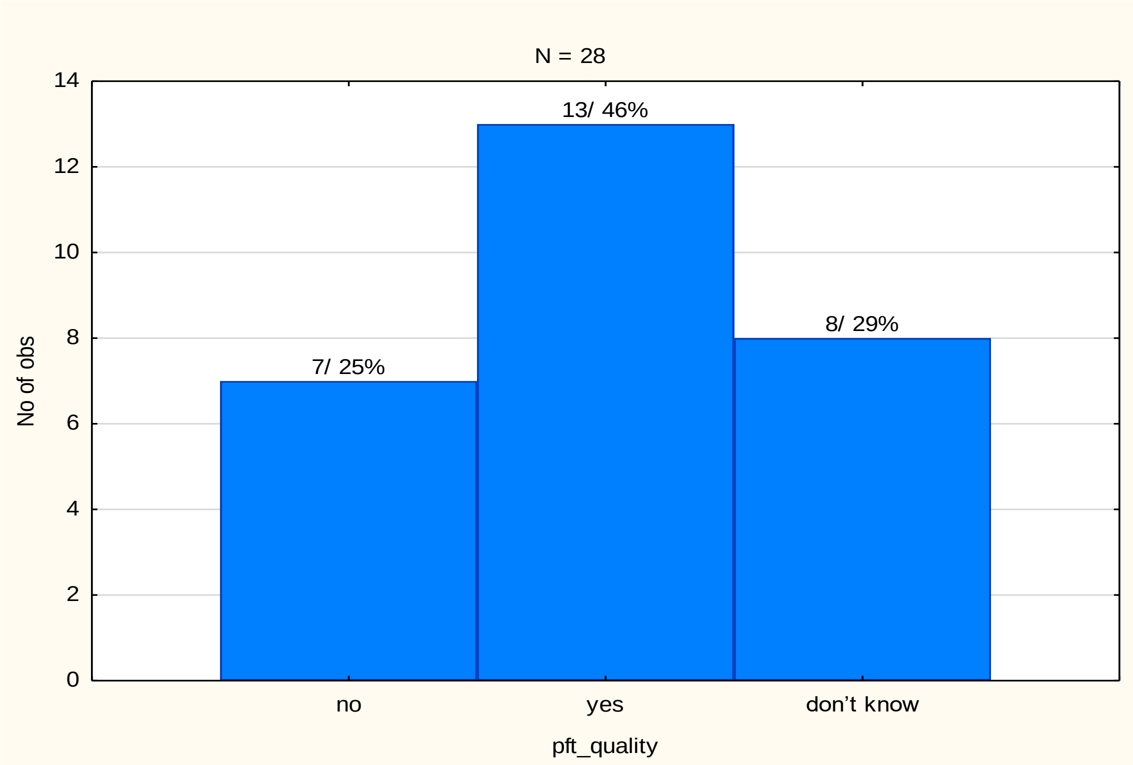

Figure 6.7 : PA technologies improved maize

A question was added concerning grid soil sampling of cultivated fields. 36% of farmers conducted grid soil samples every year, 21% every two years, 30% every three years, 9% every four years, and 3% every five years.

Table 6.1 and 6.2 illustrate the costs associated with maize production in two different regions of South Africa. Table 6.1, Table 6.2, and their calculations were generated by BFAP. Table 6.1 focuses on the Eastern Free State, while Table 6.2 shows the area around Lichtenburg in the North West in terms of a hypothetical calculation in yield increase alone, exclusive of any savings in fuel, seed, fertilizer, chemicals, and increased productivity. Looking at a 3% increase in yield which was the lower bound of the smallest increase indicated on the surveys. 21% indicated a 3%-6% increase in yield, 14% indicated a 6%-10% increase in yield, 25% indicated a 10%-14% increase in yield and 11% indicated a 14%-20% increase in yield.

Using a 3% increase in yield in the Eastern Free State would increase the average yield to 5.665 tons per hectare from 5.50 tons per hectare. Therefore, an increase in yield by an extra 165kgs per hectare equates to an increase in turnover at a nett farm gate price of R 2 181 from R11 998 to R12 357 per hectare. Over five years of a farmer planting 100 hectares per annum, this R360 per hectare increase will result in an R180 000 increase in turnover from the use of PA technology. Table 6.2 looks at the Northwest, where an increase of 3% yields an average yield increase to 4.3775 tons per hectare from 4.25 tons per hectare. This equates to an increase in yield by 127.5 kg per hectare, which yields an increased turnover at a nett farm gate price of

R2 133 from R9 064 to R9 335 per hectare per year. Over five years and 200 hectares per annum, a farmer will increase his turnover by R271 957.5 over five years.

Table 6.1: Income & cost budgets for maize, Eastern Free State - Dryland. (BFAP, 2018:14)

Eastern Free State		
Crop		Maize
Production System		Dryland
1. INCOME		
Yield: Deterministic	T/HA	5.50
SAFFEX SIMULATED PRICE / PRODUCER PRICE: 2019	R/TON	R2 949
Total deductions	R/TON	R313
Transport differential	R/TON	R253
Grade differential	R/TON	R-
Marketing & Handling	R/TON	R60
Price premiums	R/TON	R-
Net Farm Gate Price	R/TON	R2 181
GROSS INCOME	R/HA	R11 998
2. VARIABLE EXPENDITURES		
Contracting	R/HA	R-
Crop insurance	R/HA	R360
Fertilizer	R/HA	R3 017
Lime	R/HA	R424
Seed	R/HA	R1 388
Fuel	R/HA	R968
Herbicide	R/HA	R1 027
Insecticide	R/HA	R95
Fungicides	R/HA	R395
Markgeting costs	R/HA	R-
Repairs and maintenance	R/HA	R985
Casual labour	R/HA	R200
Aerial spray	R/HA	R-
Other expenditure	R/HA	R-
TOTAL VARIABLE EXPENDITURE	**R/HA**	**R8 858**
TOTAL VARIABLE EXPENDITURE	**R/TON**	**R1 611**
3.1) GROSS MARGIN:	**R/HA**	**R3 140**
3.2) GROSS MARGIN:	**R/TON**	**R571**

Table 6.2: Income & cost budgets for maize, North West: Lichtenburg region - Dryland. (BFAP, 2018:23)

North West: Lichtenburg		
Crop		Maize
Production System		Dryland
1. INCOME		
Yield: Deterministic	T/HA	4.25
SAFFEX SIMULATED PRICE / PRODUCER PRICE: 2019	R/TON	R2 393
Total deductions	R/TON	R260
Transport differential	R/TON	R197
Grade differential	R/TON	R-
Marketing & Handling	R/TON	R63
Price premiums	R/TON	R-
Net Farm Gate Price	R/TON	R2 133
GROSS INCOME	R/HA	R9 064
2. VARIABLE EXPENDITURES		
Contracting	R/HA	R-
Crop insurance	R/HA	R154
Fertilizer	R/HA	R2 121
Lime	R/HA	R325
Seed	R/HA	R678
Fuel	R/HA	R930
Herbicide	R/HA	R1 124
Insecticide	R/HA	R391
Fungicides	R/HA	R-
Markgeting costs	R/HA	R-
Repairs and maintenance	R/HA	R929
Casual labour	R/HA	R231
Aerial spray	R/HA	R-
Other expenditure	R/HA	R-
TOTAL VARIABLE EXPENDITURE	**R/HA**	**R6 884**
TOTAL VARIABLE EXPENDITURE	**R/TON**	**R1 620**
3.1) GROSS MARGIN:	**R/HA**	**R2 181**
3.2) GROSS MARGIN:	**R/TON**	**R513**

6.2 Multiple data analysis

The following section of the multiple data analysis includes all the questions that were asked where multiple answers were permissible. Of the farmers that used auto-steer, the majority of them utilised it for spraying (78%), planting (73%), fertilizer application (73%), and lime spreading (62%). A reduced number of farmers used it for primary tillage (24%), harvesting (19%), land prep (16%), and cultivating (5%).

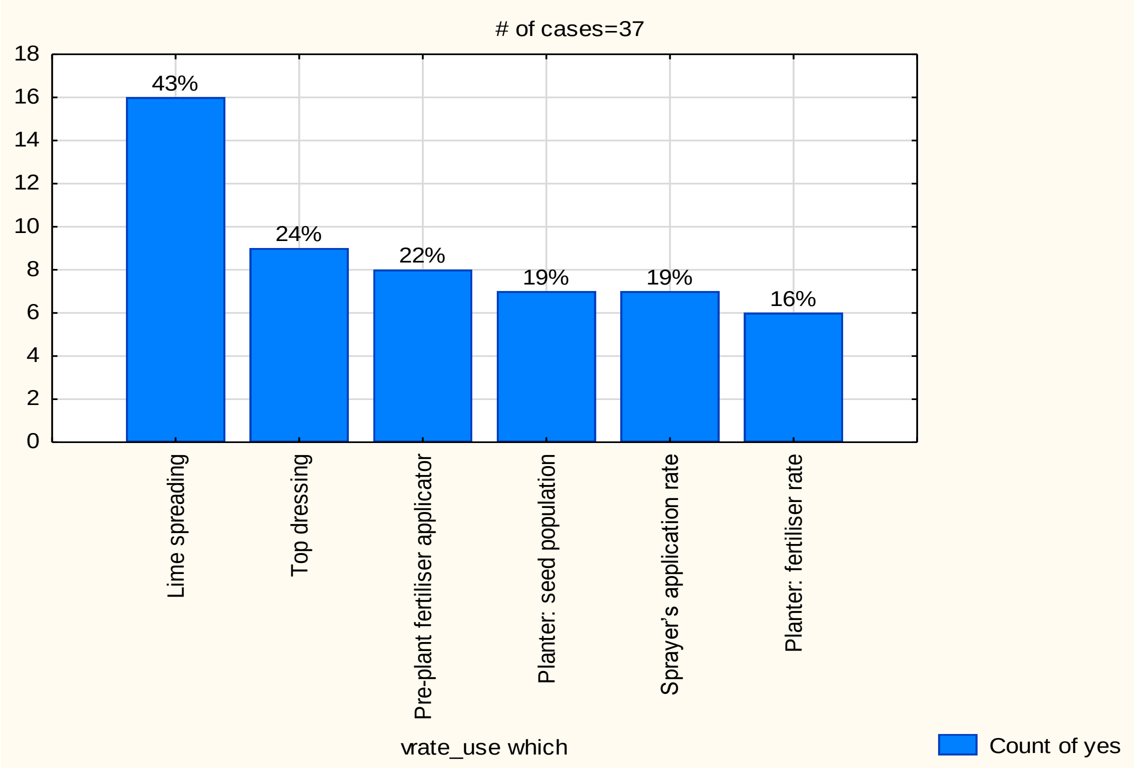

Figure 6.8: Application of VRA on different operations

Figure 6.8 illustrates the focus on VRA of lime to improve soil acidity in poorer areas of cultivated fields. This is the dominant form of VRA with 43% of all farmers in the survey conducting VRA in terms of lime, 24% of farmers that use VRA technology include the capabilities in topdressing, 22% in pre-planting fertilizer application, 19% in both planter seed population as well as sprayer application and 16% in planting fertiliser.

Of the farmers that were surveyed, 65% used a form of auto-steer/guidance, 51% made use of section control and 49% made use of VRA. 97% of farmers planted maize every year that they had been farming over the past 10 seasons. Some farmers had only planted maize for four years, however, they have only been farming for four years. In terms of section control, the most used implement with section control was sprayer application with 49% followed by lime spreading, planting seed population, and top dressing with 22% each. Figure 6.9 illustrates the implementation of section control on different applications.

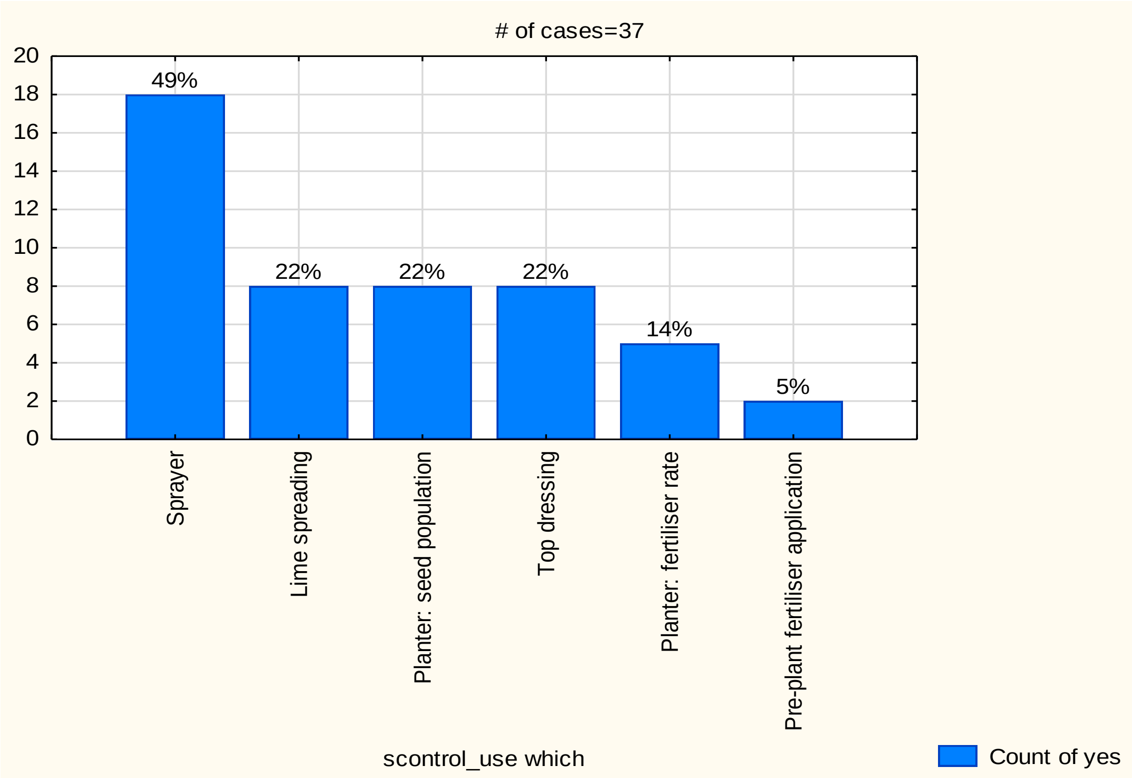

Figure 6.9 : Application of section control on different operations

One of the aspects of PA that I wanted to research is what percentage of farmers had machinery with the capability to carry out VRA, but do not use it. This indicates the presence of farm-level barriers other than that of the economic barrier. Figure 6.10 illustrates the number of farmers that have the machinery capable of implementing VRA, however, are not using it. A total of 8% of farmers have the equipment capable of

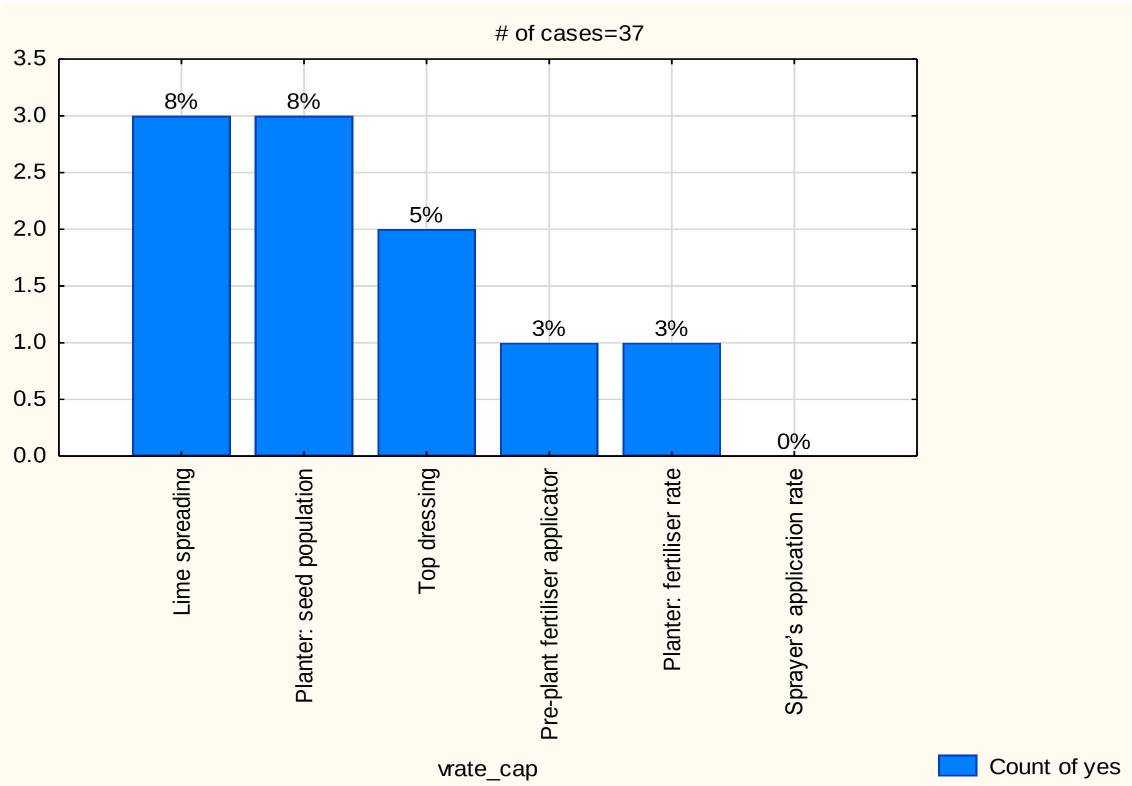

Figure 6.10 Capability to execute VRA but non-use responses

implementing VRA but do not utilize it for lime spreading and seed population at planting, 5% for top dressing, and 3% for both fertilizer application and fertilizer application at planting.

One of the considerations when implementing VRA, specifically, compared to other PA technology is how you are going to fabricate your VRA prescription maps and what data will be used. The question was asked how farmers monitor their in-field yield variance as well as what data layers they include to compile their VRA prescription maps. An aggregate of 70% of farmers use a combine yield monitor to view their in-field variance, yield monitors are followed by grid samples and year on year field records at 46%, 27% of farmers used satellite images, 22% used consultants yield estimation while 8% used non-grid soil samples and drone imagery. Figure 6.11 illustrates the popularity of various techniques which farmers used to measure in-field variability.

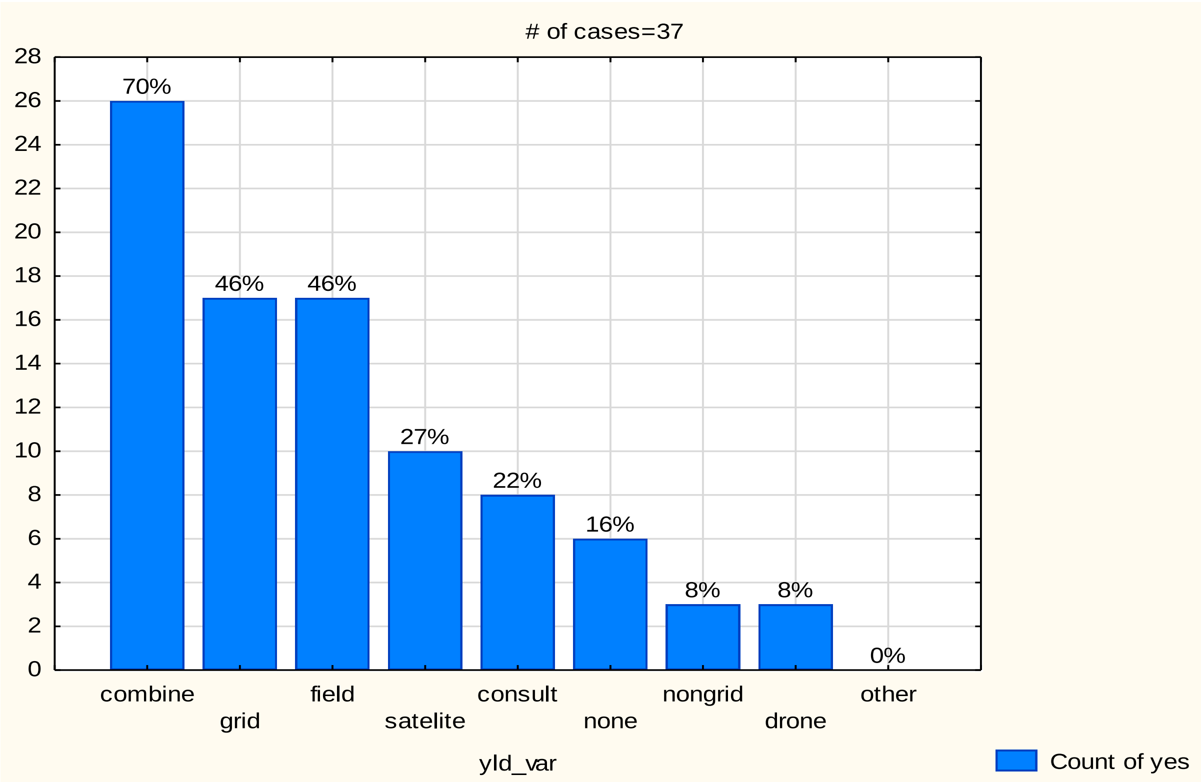

Figure 6.11 : Yield variance monitoring

Of the farmers included in the study, three were solely crop farmers. Figure 6.12 illustrates the use or non-use of VRA relating to whether or not a farmer is an exclusive cropping production system or a mixed production system. Of the three exclusive crop farmers, two (67%) did not use VRA and one (33%) did. This, however, is insignificant due to the number of respondents. Mixed farmers, on the other hand, had an inverse response, compared to that of the crop farmers, in terms of the use or non-use of VRA with 53% of the mixed farmers implementing VRA and 47% not implementing VRA.

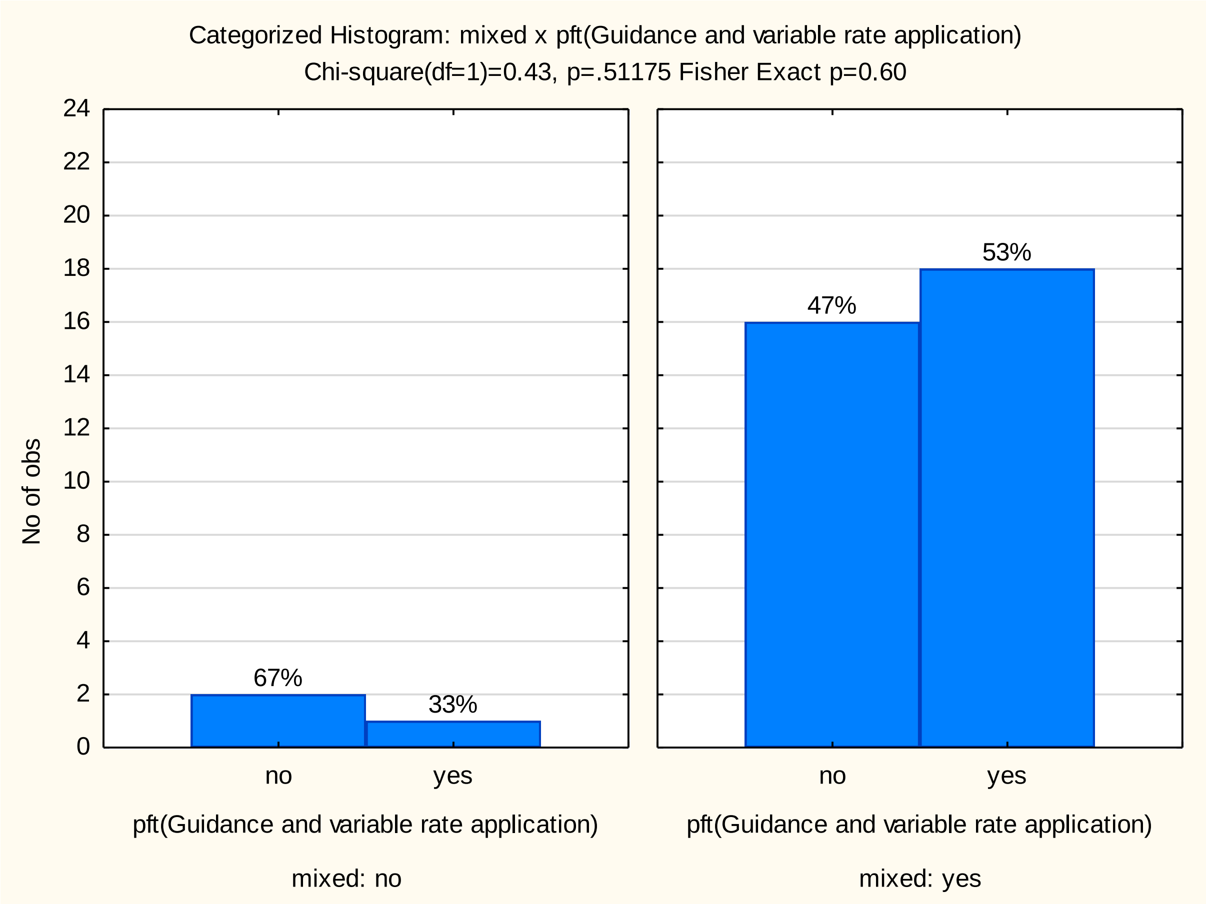

Figure 6.12 :Adoption of VRA in a relationship with mixed farming system

Chapter 7: Machine data

7.1 Machine Data

A section on machine data was included to understand how farmers view machine data and how they manage it. A total of 46% of farmers viewed machine data as 10/10 in terms of importance and 23% viewed machine data as an 8/10. Figure 7.1 illustrates the responses to what farmers thought of the importance of machine data. This is heavily weighted to the side of higher importance with 78% of farmers classifying machine data importance as a 7/10 or higher. What seemed contradicting is that from Figure 7.1 is it can be deduced that farmers believe that machine data is of high importance, however, 43% of farmers did not actively manage their machine data in any form which is illustrated in Figure 7.2.

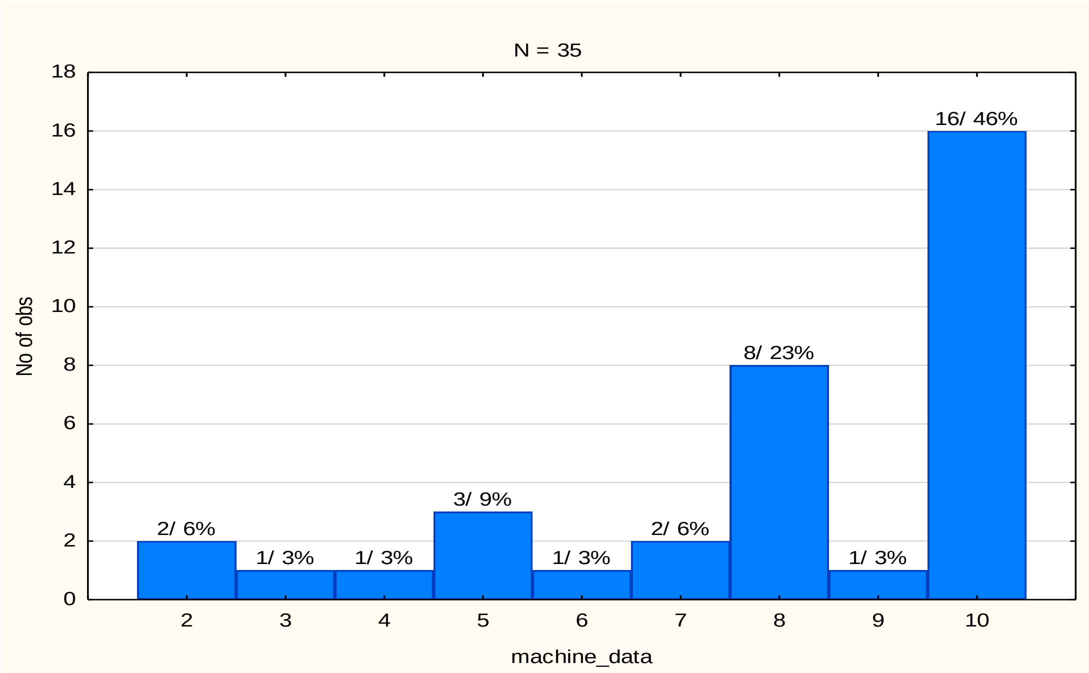

Figure 7.1 : Importance of machine data (Value/10)

Farmers had a similar view in terms of machine data privacy as well as the sharing of machine data. In Total, 60% of farmers stated that they thought the privacy of machine data was important, 20% stated it was not important. The sharing of data with a third party was 66%, although 60% of farmers said they take their data privacy seriously. This machine data is shared with a third party for them to help make informed decisions or provide assistance on a technical front such as generating VRA prescription maps or for the assistance of a consultant. Figure 7.3 illustrates the responses in terms of farmer's views on data privacy while figure 7.4 illustrates whether or not farmers share their machine data with a third party or not.

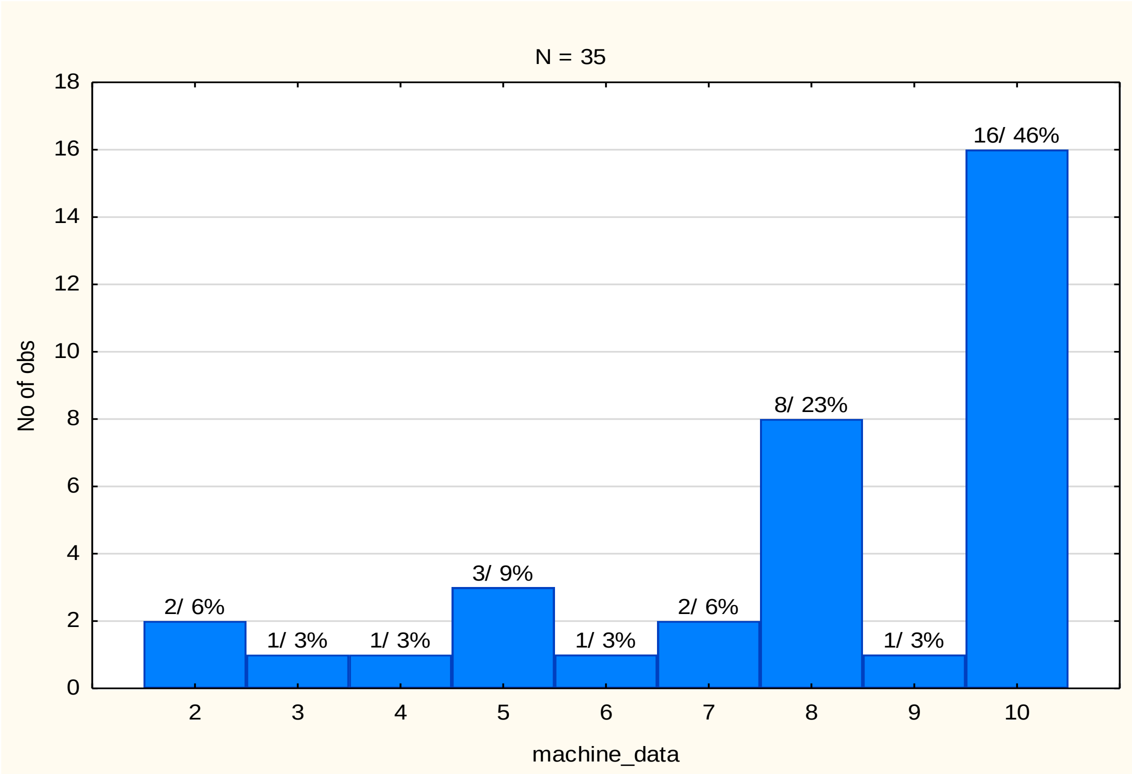

Figure 7.2: Data management from maize farmers in South Africa

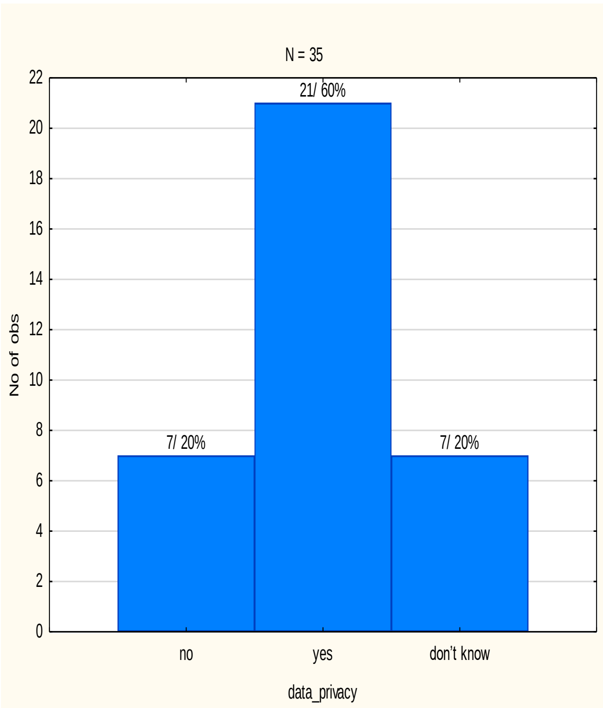

Figure 7.3: Farmers view on data privacy

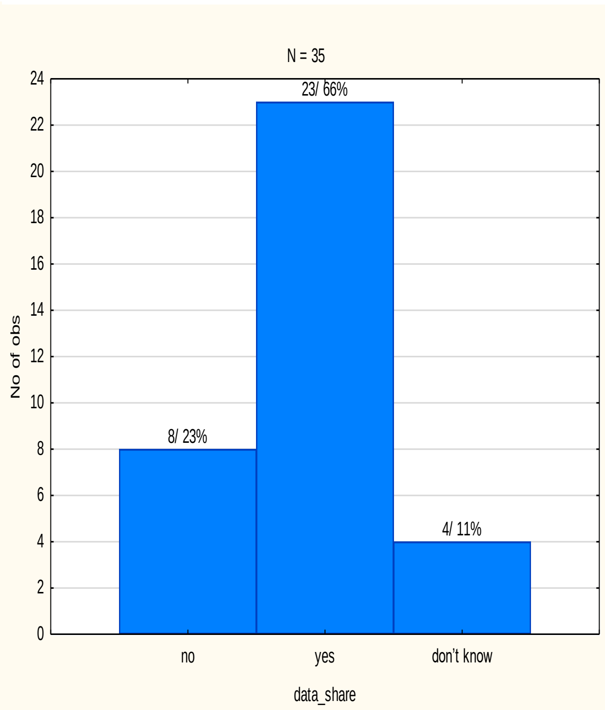

Figure 7.4: Farmers who share machine data with a third party

Chapter 8: Summary and Conclusion

8.1 Summary

The main questions that I aimed to answer through my research include what is the current adoption level of PA technology by South African maize farmers? What are the main barriers that prevent farmers from adopting or expanding the use of PA technology? What are the perceived benefits highlighted by farmers who use PA technology? And what are farmer's views on machine data and the management of machine data?

8.1.1 Adoption of PA

In total, 65% of farmers implemented a form of guidance or auto-steer, 51% section control and 49% of respondents implement VRA across my sample of thirty-seven farmers.

8.1.2 Farm-level barriers to PA

My primary hypothesis was that adoption rates of PA technology by maize farmers are driven by farmer characteristics such as age, level of education, production attributes (e.g., Hectares planted each season, farm turnover), and beliefs regarding PA technology.

The independent variables used in the logit model were based on previous studies and their findings. I, therefore, included age, education, farm location on a provincial level, the quantity of hectares planted, annual farm turnover and mixed farming practises. Matela and Helm (2002:2005) both found that there was a reluctance to adopt PA technology for farmers above the age of 45 years old. Jacobs, Van Tol, and Du Preez, (2018) study of the Schweizer-Reneke region found a similar trend however Jacobs et al found there to be a reluctance to adopt PA technology over the age of 55 years old. In my research, there was no statically significant difference between the age of a farmer and the use or non-use of PA technology. Nonetheless, the positive relationship between farmer age and the adoption of PA technology leads to the assumption that older farmers are more likely to adopt PA technology compared to younger farmers which are contradicting to the previous studies in both international and South African literature.

There was a similar trend with the results of the relationship between education and the adoption of PA technology. Matela and Helm (2002:2005) found there to be a higher willingness to adopt PA technology with a higher level of education. My research illustrated a similar result to the relationship between age and the willingness to adopt PA technology, showing that the average level of education of farmers that implement PA technology is lower than that of farmers with a higher average level of education.

There was no statistically significant relationship between planting practice (no-till/conventional) and the adoption of PA technology. Similarly, with the province in which the farm was located, mixed farming enterprises and the adoption of PA technologies.

There was a correlation between the hectares planted, annual farm turnover, and the adoption of PA technology respectively. Economies of size allow bigger grain farmers to adopt PA technology more easily as the initial investment is spread over a larger base.

My secondary hypothesis was that the main farm level barriers to adopting PA technology are not an economic barrier in terms of financing the necessary hardware and software but rather the management, manipulation, and implementation of data (agronomic barriers). There were a number of farmers that seem to be uninformed with regards to the workings of PA technology.

8.1.3 Perceived benefits of PA

In terms of VRA non-use, 56% of the farmers that do not use VRA agree that it will help their farm management, 83% agree that it will increase in-field speed and thus result in greater productivity. Mixed results were obtained from questions where farmers did not have sufficient knowledge and/or experience with PA, as shown with the results on the execution of prescription maps, generation of prescription maps, and other activities relating to data management. With respect to adopting section control over the short to medium term, 47% agreed and 21% of respondents agreed strongly that they intend to equip their machinery with section control technology during their next machinery replacement cycle. Thus, there is a trend towards the greater adoption of section control as a form of PA.

Farmers that use PA technology see clear benefits in the sense of improved yield, decreased yield variability, efficient input and resource allocation, improved speed in-field, and productivity. Another question considered was whether farmers had the perception that PA technology influence the quality of grain produced. This question had a mixed response with the majority at 46% of the farmers saying yes, 25% saying no and 29% saying they do not know.

8.2 Recommendations

My research shows that the adoption was 65% for guidance, 51% for section control, and 49% for VRA. This compares favourably to the international literature which estimates the aggregate adoption of these technologies at between 29% for VRA and 59% for guidance in maize production. However, the South African adoption rates still leave ample room for improvement especially amongst smaller farms, which were underrepresented in this study. With respect to the drivers of adoption, this study had inconclusive and, in some instances, contradictory results (e.g., age and education) relative to the international literature.

However, I found that farmers who use PA technology have the perception that the technology has clear benefits with respect to productivity and efficiency. Concerning the farmers not using PA, responses were mixed to the extent that it created the impression that this subset of farmers is uninformed about the benefits and for some farmers the suitability of the technology given the computer literacy of their operators.

8.2.1 Suppliers

Equipment suppliers, input suppliers as well as precision agriculture consultants could benefit from marketing systems in which the farmers can get a better understanding of the benefits included in PA technology, as well as more information in some of the areas where there was doubt from farmers in terms of data acquisition, manipulation as well as the implementation of the relevant data on a farm level.

The results from the surveys indicate that the perceived benefits of PA technology outweigh that of the farm-level barriers. Farmers should try to look at what their cost would be over five to ten years, in terms of feasibility, instead of looking at the initial capital outlay. It is difficult to measure the efficiency improvements in terms of increased productivity and reduced driver fatigue, these variables although intangible, do play a big role in equipment management.

The perceived benefits from using PA were clear with the majority of responses in favour of PA saving seed, fertilizer, and fuel, at the same time providing the ability to increase in-field speed and therefore improve not only input efficiency but also time efficiency. With the rising input prices, it becomes more and more sensible for farmers to implement these forms of PA technologies, which will allow them to not only produce a better crop but also allow them to do so more efficiently and sustainably. Along with the ever-changing weather environment and often a smaller planting window, PA technology allow farmers to conduct relevant tasks in a timely manner.

8.2.2 Policy implications

There is always scope for policy improvement in the agriculture sector, especially with regards to how we produce food for the country. As stated in my introduction, Khosla and Alley (1999) suggest that VRA does not only allow for the efficient allocation of inputs but also reduce the environmental impact of inputs. This is done by applying the correct quantity of seed, fertilizer, and chemicals to a specific soil type and soil potential across a single field. Single rate application can often over-apply fertilizer and chemicals to a specific area of the field, as the single rate refers to the average soil conditions of the field and not the specific conditions within the field. With a single rate application, there is often leaching of chemicals and fertilizers which can be degrading to the environment if not applied correctly. It would therefore be beneficial for the Department of Agriculture, Forestry and Fisheries to implement a subsidy for farmers practising VRA, as well as contractors, providing the opportunity for small farmers to execute VRA without having to purchase the technology themselves. There is also scope for the implementation of a subsidy regarding the other forms of

PA technology where not only inputs are perceived to be used more efficiently but also that of fuel specifically. If farmers are using fuel more efficiently it will have a reduced impact on carbon dioxide emissions and be better for the environment; therefore, it could be beneficial for the Department of Agriculture, Forestry, and Fisheries to implement a subsidy or incentive program for the use of section control, guidance and not only VRA.

A possible policy for the encouragement of the adoption of PA technology could allow the Department of Agriculture, Forestry, and Fisheries to sponsor training programs for operates on farms to enable them to obtain an education on the systems and their usability. This will help reduce the barrier of operator literacy concerning PA technology.

8.3 Suggestions for future research

Further studies in this line would include the possible specific calculated benefits of PA technology which dives deeper into what was covered in the perceived benefits in this study. A larger sample of farmers for the PA technology would be beneficial to give more precise results from a statistical aspect. It would be beneficial in future studies to attempt to obtain more data from farmers in terms of decision making and historical data, as well as information on machinery which correlates to the historical data. Beneficial historical data would include type and quantity of fertilizers, the seed used in each season as well as rain records and prices for grain through the relevant seasons.

A profound variable in the perceived benefits from PA technology weighs heavily on numerous independent variables that are difficult to quantify directly to PA technology and the benefits thereof, with the main driving factor being the weather.

Due to the various methods of acquiring data through emails, monkey surveys, in-person and telephonically interviews, there were some instances where farmers miss understood the question on email and monkey survey platforms. On the monkey surveys and emails, farmers left out questions which they could not feel they could answer, however, those were also the questions in which I intended to understand their view and "gut feel" on a certain aspect. Although gathering data on an interview is time-consuming and arduous, it is the most reliable way of obtaining the correct data in the form in which you prefer. Although the Covid-19 pandemic played a role in having to try different mechanisms of obtaining data, if possible, I would suggest trying to gain all the data from in-person interviews.

References

Buick, R. 1997. Precision agriculture: an integration of information technologies with farming. *Proceedings of the NZ Plant Protection Conference*. 50:176–184.

DeMaris, A. 1992. Logit modelling practical application. *Sage university paper series on Quantitative Applications in Social Sciences*. 07–086.

DAFF (Department of agriculture. forestry. and fisheries)., 2017. A profile of the South African maize market value chain. *Journal of Chemical Information and Modeling*. 53(9):1689–1699.

Davis. G; Cassady. W; Massey.R. 1998. *Precision Agriculture: An Introduction*. Available: https://extension.missouri.edu/publications/wq450.

Dechant, H. 1999. *21st Century Farming*. Available: https://scholar.google.com/scholar_lookup?title=21st century farming. In InfoAg99&author=H. Dechant&publication_year=1999.

de Waal, H.O., Combrinck, W.J., Howard, M.D., and Fouché, H.J. 1990. *the impact of climate on veld (natural pasture or rangeland) and animal production*.

DHET (Department of higher education and training). 2020. *agriculture sector education training authority*. Available: https://www.agriseta.co.za/.

Doerge, T.A. 2005. Nitrogen measurement for variable-rate N management in maize. *Communications in Soil Science and Plant Analysis*. 36(1–3):23–32.

Duffy, M. 2009. Economies of size in production agriculture. Journal of hunger and environmental nutrition 4(3-4) pages 375 - 392.

Haarhoff, S.J; Kotze, T.N; Swanepoel, P.. 2020. A prospectus for sustainability of rainfed maize production systems in South Africa. *Crop Science*. 60(1):14–28.

Helm, C. (2005). precision agriculture in South Africa. farmtech 2006 proceedings. pp76-80.

Hindle, A. 2013. *Research Point: ANOVA Explained*. Available: https://en-author-services.edanzgroup.com/blogs/statistics-ANOVA-explained#:~:text=ANOVA is used to compare, amount of variation within groups.

Hosmer, D.W., Lemeshow.S. 2012. Applied Logistic Regression. *Technometrics*. 2:1–7, 47–56.

Jacobs, A.J., van Tol, J.J. & Du Preez, C.C. 2018. Farmers perceptions of precision agriculture and the role of agricultural extension: a case study of crop farming in the Schweizer-Reneke region, South Africa. *South African Journal of Agricultural Extension*. 46(2):107–118. Available:

John Deere sub-Saharan Africa. 2020. *precision ag technology*. Available: https://www.deere.com/sub-saharan/en/technology-products/precision-ag/?panel=apply [2020, August 31].

Lowenberg-DeBoer, J., Erickson, B. 2019. Setting the Record Straight on Precision Agriculture Adoption. *Agronomy Journal*. 111(4):1552–1569.

Maine, N., Lowenberg-DeBoer, J., Nell, W.T. & Alemu, Z.G. 2010. Impact of variable-rate application of nitrogen on yield and profit: A case study from South Africa. *Precision Agriculture*. 11(5):448–463.

Maluleke, I. 2019. *Looking back and ahead at the maize price*. Available: https://www.grainsa.co.za/looking-back-and-ahead-at-the-maize-price#:~:text=South Africa consumes an average, of about 5 t%2Fha. [2020, August 25].

Maqsood, M., Abid, A.A., Iqbal, A. & Hussain, M.I. 2001. Effect of Variable Rates of Nitrogen and Phosphorus on Growth and Yield of Maize (Golden). *Online Journal of Biological Sciences*. 1(1):18–20.

Matela, N. 2002. the status of precision agriculture in South Africa. unpublished m.sc. dissertation. university of the free state, Bloemfontein, South Africa.

Nselin. L, Bongiovanni. R, & Lowenberg-DeBoer.J, 2004. a spatial econometric approach to the economics of site -s specific nitrogen management in corn production. 86(August):675–687.

Plant, R.E. 2000. *Precision agriculture can increase profits and limit environmental impacts*. Available: http://calag.ucanr.edu/Archive/?article=ca.v054n04p66 [2019, September 15].

Robertson, M., Carberry, P., and Brennan. L, 2009. Economic benefits of variable rate technology : case studies from Australian grain farms. 799–807.

Rüsch, P.C. 2001. Precision agriculture in South Africa. The University of Pretoria. DOI: 10.12775/LLP.2013.006.

Robert, P.C. 2002. Precision agriculture: a challenge for crop nutrition management. In *Progress in Plant Nutrition: Plenary Lectures of the XIV International Plant Nutrition Colloquium: Food security and sustainability of agro-ecosystems through basic and applied research*. W.J. Horst, A. Bürkert, N. Claassen, H. Flessa, W.B. Frommer, H. Goldbach, W. Merbach, H.-W. Olfs, V. Römheld, B. Sattelmacher, U. Schmidhalter, M.K. Schenk, & N. v. Wirén, Eds. Dordrecht: Springer Netherlands. 143–149.

Rodriguez, J.M., Molnar, J.J., Fazio, R.A., Sydnor, E. & Lowe, M.J. 2009. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems*.

Ross Kingwell, Fuchsbichler. A, 2011. The whole-farm benefits of controlled traffic farming: An Australian appraisal. *Agricultural Systems*. (104):513–521.

SAGL. 2017. *South African Maize Crop Quality report 2016/17 season*. Available: https://sagl.co.za/wp-content/uploads/Reports/Maize/2016.2017/Maize-Crop-Report-2015-2016.pdf.

SAGIS. 2020. Maize products - Historic information October 2020.

Schimmelpfennig, D. 2016. Farm Profits and Adoption of Precision Agriculture. *Economic Research Report*. (October 2016):46.

Statista. 2020. *Maize production in South Africa 2018/2019, by province Published by Statista Research Department, Aug 18, 2020, In 2018/2019, the total production of maize in South Africa amounted to 10.51 million metric tons. Free State was the province with the highest*. Available:

Statistical Solutions. 2019. *What is Logistic Regression*? Available: https://www.statisticssolutions.com/what-is-logistic-regression/ [2020, May 29].

The Fertilizer Institute. 2014. *Fertilizer 101: The Big 3 - Nitrogen, Phosphorus, and Potassium*. Available: https://www.tfi.org/the-feed/fertilizer-101-big-3-nitrogen-phosphorus-and-potassium [2020, February 14].

Thrikawala, S., Weersink, A., Kachanoski, G. & Fox, G. 1999. Economic Feasibility of Variable-Rate Technology for Nitrogen on Corn. *American Journal of Agricultural Economics*. 81(4):914.

Trytsman, G., 2018. *Benefits of winter cover crops in a mixed farming system*.

Walsh, A. 1987. Teaching understanding and interpretation of Logit regression. *Teaching sociology*. 15(April):178.

Appendix A: English Survey

2020 South African Maize Variable Application Survey

Please answer the following questions about the primary decision-maker on the farm. Answers to all questions will remain strictly confidential.

Section A: Biographical and farm information

1.In what year were you born?

____

2.How many years have you been farming?

____

3.Where are most of your farm located?
Province___________________________Municipality______________________
Closest town_______________________

4.What is the highest level of education that you have achieved?

A. Less than matric
B. Matric
C. Diploma
D. Bachelor's degree
E. Master's degree
F. PhD degree

5.Please check the category that best reflects the turnover of your farm in 2019

A. R1 000 000 and less
B. Between R1 000 001 and 2 000 000
C. Between R2 000 001 and 5 000 000
D. Between R5 000 001 and 10 000 000
E. Between R10 000 001 and 20 000 000
F. Between R20 000 001 and 30 000 000
G. More than R30 000 000

6.What is your current farming practises?

[a] Mixed farming (Livestock and crops)	A. wool sheep B. meat sheep C. dual-purpose sheep D. beef cattle E. dairy F. goats
[b] Crop production only	☐

7.Did you grow maize during these seasons?

- ☐ 2009/10
- ☐ 2011/12
- ☐ 2012/13
- ☐ 2013/14
- ☐ 2014/15
- ☐ 2015/16
- ☐ 2016/17
- ☐ 2017/18
- ☐ 2018/19
- ☐ 2019/20

8.Which other field crops do you grow?

- ☐Soybeans
- ☐Sunflower
- ☐_______________
- ☐_______________
- ☐Sorghum
- ☐Wheat
- ☐________________
- ☐________________

9.What is your current crop rotation system if applicable? Please indicate the rotation of a typical field e.g.

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Maize	Maize	Soybeans	Maize	Maize	Soybeans

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6

10.What planting practise do you use for your maize?

Conventional tillage (Cultivate more than 20% of the surface area)
Conservation tillage or Minimum tillage (Minimal soil disturbance but with mechanical weed control)
Zero tillage (No mechanical weed control)

11.How many hectares of **maize** did you plant during the seasons below and what was your average yield?

	2016/17		2017/18		2018/19	
	ha	Average yield	ha	Average yield	ha	Average yield
Dryland						
Irrigated						

12.How do you measure yield variability on your farm? (Check all that apply)

Combine monitor with yield mapping
Non-grid sampled soil maps
Grid sampled soil maps
Year-to-year field records
Consultants' estimates
Satellite imagery
Aerial or drone photography
I do not measure in-field variability
Other (specify) ________________

13.I currently use the following precision agriculture technologies (Check all that apply)

A. Guidance/autosteer
B. Guidance and section control
C. Guidance and variable rate application
D. I use all three

14.For which field operations would you use a GPS guidance system? (Check all that apply)

- ☐Land prep – levelling and drainage
- ☐Lime spreading
- ☐Primary tillage
- ☐Planting
- ☐Spraying
- ☐Fertiliser application
- ☐Cultivating
- ☐Harvesting

15.Do you use paid for GPS signals? And if so, since when?

A.Yes, since_____________
B.No

16.Do you use RTK / RTX (physical base station)? And if so, since when?

A.Yes, since_____________
B.No

17.Where do you get your precision agriculture information from? (Check all that apply)

A.Machinery supplier
B.Input suppliers
C.Precision agriculture consultant
D.Extension officer
E.Other Farmers
F.Shows/ farmer days
G.Internet
H.News/ Media
I.Other: -_______________________

18.Which one of the following would you deem as your **most important** source of precision agriculture information?

A.Machinery supplier
B.Input suppliers
C.Precision agriculture consultant
D.Extension officer
E.Other Farmers
F.Shows/ farmer days
G.Internet
H.News/ Media
I.Other:-_______________________

19.Do you currently make use of variable rate application?

A. I don't use variable rate application
B. I do not use it now but intend to do so in the next two years
C. I've used it in the past but have stopped
D. I do use it

20.Regarding the **variable rate application**, please circle the relevant answer to the questions below:

a.I use variable rate application for….

Lime spreading	Yes / No
Pre-plant fertiliser applicator	Yes / No
Planter: seed population	Yes / No
Planter: fertiliser rate	Yes / No
Topdressing	Yes / No
Sprayer's application rate	Yes / No

b.My …………….. has the capability to do variable rate application **but I do not use it.**

Lime spreader	Yes / No
Pre-plant fertiliser applicator	Yes / No
Planter: seed population	Yes / No
Planter: fertiliser rate	Yes / No
Topdressing implement	Yes / No

21.Do you currently make use of section control?

A. I don't use section control
B. I do not use it now but intend to do so in the next two years
C. I've used it in the past but have stopped.
D. I do use it

22.Regarding **section control**, please circle the relevant answer to the questions below:

c.I use section control for…

Lime spreading	Yes / No
Pre-plant fertiliser application	Yes / No
Planter: seed population	Yes / No
Planter: fertiliser rate	Yes / No
Topdressing	Yes / No
Sprayer	Yes / No

d.My …………….. has the capability to do section control **but I do not use it.**

Lime spreader	Yes / No
Pre-plant fertilizer applicator	Yes / No
Planter: seed population	Yes / No
Planter: fertiliser rate	Yes / No
Topdressing implements	Yes / No
Sprayer	Yes / No

Section B: Reasons for not using variable rate application.

Please answer the following questions if you do not use VRA.

23.Please complete the following statements that best match your experience with the variable rate application.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
A. VRA will not / does not help me to improve on my current practices since I manage my farm on a per-field basis					
B. It is too expensive to have VRA prescription maps generated.					
C. It is too expensive to purchase the necessary machinery and hardware to execute VRA maps					
D. The hardware used to execute VRA is not dependable and thus causes field delays					
E. I've used VRA in the past but did not see the benefits thereof.					
F. My operators are not computer literate and thus cannot execute VRA					
G. I struggle to get the prescriptions (maps) on the tractor					
H. I do not have a good representative to help me write and implement the necessary maps					

24. Please complete the following statements that best match your experience with section control.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
A. I do not own the necessary equipment to do section control but would use it if I had it					A
B. It is not necessary for the scale at which I farm at					
C. Section control equipment is unaffordable					
D. Section control is less accurate than advertised					
E. I would add section control in my next machine replacement cycle					

Section C: Benefits of using various technologies.

Please answer the following questions if you use guidance, section control, variable rate application, or all three

25. Please complete the following statements that best match your experience with the variable rate application.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
A. Using these technologies improves yield					
B. Using these technologies decreases yield variability					
C. Using these technologies saves fuel					
D. Using these technologies saves seed and fertiliser					
E. Using these technologies improves field speed, results in greater productivity					
F. Using these technologies helps a single driver to get more done through reduced fatigue					

26. Have you ever experienced any improvements in ***maize quality*** using these technologies?

□ Yes □ No □ Don't know

27. What is your best estimate of the yield increase because of using these technologies?

A. <3%
B. 3 to 6%
C. 6 to 10%
D. 10 to 14%
E. 14 to 20%
F. More than 20%
G. I don't know

28. What is your best estimate of the decrease in yield variability because of using these technologies?

A. <3%
B. 3 to 6%
C. 6 to 10%
D. 10 to 14%
E. 14 to 20%
F. More than 20%
G. I don't know

29.

If you use VR, which of the following data

sources are used to generate your variable rate application maps?

Variable Rate Decision	1. Yield Monitoring with GPS	2. Aerial/ Satellite Infrared Imagery	3. Grid soil sampling	4. Green Seeker/Weed seeker	5. Electrical Conductivity /Soil scanning
A. Soil pH					
B. Soil fertility					
C. Seeding					
D. Irrigation					

30. Who typically generates your variable rate application maps?

A. You or a family member
B. Precision agriculture consultant
C. Fertilizer or Chemical Dealer
D. Other (specify)____________________

31. How often do you grid sample your fields if applicable? Every __________ years

Section D: Please answer the following questions relating to your farming data management strategy

32. On a scale from one to ten, how important is machine collected data for your farm? This includes yield- and application maps, navigation lines, etc.

33. How do you manage your machine collected data?

A. I do not actively manage my machine data
B. I export the data to a flash disk for future reference
C. I export the data to a flash disk and process the data using the manufacturer provided desktop software
D. I export the data to a flash disk and upload the data to a cloud-based / online platform for processing and storage (e.g. JD Link, Operations centre, Connected farm, Field View)
E. The machine automatically uploads the data to loud based / online platform (e.g. JD Link, Operations centre, Connected farm, Field View)

34. Do you think it's important to control the access to your machine data? I take privacy seriously

A. Yes
B. No
C. I don't know

35. Are you currently sharing your machine data with a third party?

A. Yes
B. No
C. I don't know

Appendix B: Afrikaans survey

2020 Suid Afrika Mielie Presisie boerdery vraelys

Beantwoord asseblief al die vrae hieronder vanuit die perspektief van die primêre besluitnemer op plaas. Die antwoorde op alle vrae sal streng konfidensieel bly.

Afdeling A: Biografiese en plaas informasie

36.Geboorte Jaar?

____

37.Hoe lank boer u al?

____

38.Waar is jou plaas geleë?

Province__________________________Municipalitate______________________

Naaste Dorp_______________________

39.Hoogste kwalifikasie?

G. Minder as matriek
H. Matriek
I. Diploma
J. Baccalaureus graad
K. Meestersgraad
L. Doktorsgraad

40.Waar pas u in terme van plaas omset

A.R1 000 000 en minder
B.Tussen R1 000 001 en 2 000 000
C.Tussen R2 000 001 en 5 000 000
D.Tussen R5 000 001 en 10 000 000
E.Tussen R10 000 001 en 20 000 000
F.Tussen R20 000 001 en 30 000 000
G.Meer as R30 000 000

41.Waar mee boer u?

[a] Gemengde boerdery (Vee en gewasse)	G. wolskape H. Vleisskape I. Dubbeldoelskape J. Vleisbeeste K. Melkbeeste L. Bokke
[b] Slegs saaiboerdery	☐

42.Het u mielies geplant gedurende die hierdie seisoene?

- ☐ 2009/10
- ☐ 2011/12
- ☐ 2012/13
- ☐ 2013/14
- ☐ 2014/15
- ☐ 2015/16
- ☐ 2016/17
- ☐ 2017/18
- ☐ 2018/19
- ☐ 2019/20

43.Watter ander gewasse verbou u tans?

- ☐Sojabone
- ☐Sonneblom
- ☐_______________
- ☐_______________
- ☐_______________
- ☐Sorghum
- ☐Koring
- ☐________________
- ☐________________
- ☐________________

44.Wat is u huidige gewasrotasiestelsel? Dui asseblief die rotasie aan op 'n tipiese land bv.

Jaar 1	Jaar 2	Jaar 3	Jaar 4	Jaar 5	Jaar 6
Mielies	Mielies	Sojabone	Mielies	Mielies	Sojabone

Jaar 1	Jaar 2	Jaar 3	Jaar 4	Jaar 5	Jaar 6

45.Watse bewerkings sisteem volg u?

A.Konvensionele bewerking(Meer as 20% van die grondoppervlak word bewerk)
B.Bewaringsboerdery-Minimum bewerking (Minimale bewerking met meganiese onkruid beheer)
C.Geenbewerking (Geen meganiese onkruidbeheer)

46.Hoe veel hektaar **mielies** het u geplant gedurende die onderstaande seisoene en wat was die gemiddelde opbrengs?

	2016/17		2017/18		2018/19	
	ha	Gemiddelde opbrengs	ha	Gemiddelde opbrengs	ha	Gemiddelde opbrengs
Droëland						
Besproeiing						

47.Hoe meet u opbrengs variasie op u plaas? (Merk al die toepaslike)

A.Stropermonitor met opbrengs kartering
B.Nie "grid" grond-monster kaarte
C."Grid" grond-monster kaarte
D.Jaar-tot-Jaar plaas rekords
E.Konsultant se skatting
F.Satellietbeelde
G.Vlieg of hommeltuig kaarte/fotos
H.Ek meet nie opbrengs variasie nie
I.Ander (spesifiseer) ______________

48.Ek gebruik

- ☐ Selfbestuur / autosteer
- ☐ Autosteer en seksiebeheer
- ☐ Autosteer en veranderlike koers toepassing
- ☐ Ek gebruik al drie

49.Waarvoor gebruik u 'n GPS-stelsel? (Merk al die toepaslike)

A.Grond-voorbereiding, gelykmaak en dreinering
B.Kalkstrooi
C.Primêre grondbewerking
D.Plant
E.Spuite
F.Kunsmistoediening
G.Skoffel
H.Oes

50.Maak u van ‘n betaalde GPS-sein gebruik? Indien wel, sedert wanneer?

A.Ja, vanaf_____________
B.Nee

51.Gebruik u RTK/RTX (basisstasie/internet korreksiefaktor)? Indien wel, sedert wanneer?

A.Ja, vanaf _______
B.Nee

52.Waar bekom u presisieboerdery inligting?

A.Trekkerhandelaar
B.Insetverskaffer
C.Presisieboerdery-konsultant
D.Voorligter
E.Ander boere
F.Skou/boeredag
G.Internet
H.Nuus/Media
I.Ander:______________________

53.Watter een van die volgende sou jy as jou **belangrikste bron** van presisieboerdery inligting ag?

A.Trekkerhandelaar
B.Insetverskaffer
C.Presisieboerdery-konsultant
D.Voorligter
E.Ander boere
F.Skou/boeredag
G.Internet
H.Nuus/Media
I.Ander:______________________

54.Maak u gebruik van **varieerbare-toediening** (VT)? “Variable rate application”

A. Ek maak nie van varieerbare-toeding gebruik nie
B. Ek maak nie tans daarvan gebruik nie maar beoog om dit binne die volgende twee jaar te doen
C. Ek het van varieerbare-toediening gebruik gemaak maar het dit gestaak
D. Ek maak van varieerbare-toediening gebruik.

55.Aangaande **varieerbare toediening**, antwoord die volgende vrae:

a.Ek gebruik varieerbare toedining vir:

Kalktrooi	Ja / Nee
Voorplant kunsmistoediening	Ja / Nee
Plant: plantpopulasie	Ja / Nee
Plant: kunsmis	Ja / Nee
Topbemesting	Ja / Nee
Spuit hoeveelheid	Ja / Nee

b.My .... **het die vermoë** om varieerbare toedining te doen **maar ek gebruik dit nie**

Kalktrooier	Ja / Nee
Voorplant kunsmistoediener	Ja / Nee
Plant: plantpopulasie	Ja / Nee
Plant: kunsmis	Ja / Nee
Topbemesting implement	Ja / Nee
Spuit	Ja / Nee

56.Maak u tans gebruik van **seksiebeheer**?

A. Ek gebruik nie seksiebeheer nie
B. Ek gebruik nie tans seksiebeheer nie maar ek beplan om binne die volgende twee jaar daarvan gebruik maak
C. Ek het in die verlede van seksiebeheer gebruik maar doen nie meer nie
D. Ek gebruik seksiebeheer

57.Aangaande **sesksiebeheer**, anwoord die volgende vrae:

a.Ek gebruik seksiebeheer vir:

Kalktrooi	Ja / Nee
Voorplant kunsmistoediening	Ja / Nee
Planter saadplasing	Ja / Nee
Planter: kunsmis plasing	Ja / Nee
Topbemesting implement	Ja / Nee
Spuit	Ja / Nee

b.My.......... het die vermoe om seksiebeheer te doen **maar ek geruik dit nie**.

Kalktrooier	Ja / Nee
Voorplant kunsmistoediener	Ja / Nee
Plant: plantpopulasie	Ja / Nee
Plant: kunsmis	Ja / Nee
Topbemesting implement	Ja / Nee
Spuit	Ja / Nee

Afdeling B: Rede waarom u nie van varieerbare toediening gebruik maak nie.

Antwoord die volgende vrae as u nie van varieerbare toediening (VT) gebruik maak nie.

58.Voltooi asseblief die onderstaande standpunte wat u ervaring met varieerbare toeding (VT) die beste beskryf:

	Verskil sterk	Verskil	Neutraal	Stem saam	Stem sterk saam
VT sal my nie help om my praktyke te verbeter nie, aangesien ek my plaas op ‘n per land basis bestuur	☐	☐	☐	☐	☐
Dit is te duur om VRA voorskrif-kaarte te laat genereer	☐	☐	☐	☐	☐
Dit is te duur om die nodige masjinerie en hardeware te koop om VT-kaarte mee uit te voer	☐	☐	☐	☐	☐
Die harde-/sagteware wat gebruik word om VT uit te voer is nie betroubaar nie en veroorsaak vertragings op die land	☐	☐	☐	☐	☐
Ek het VT al in die verlede gebruik maar het nie die voordele daarvan gesien nie	☐	☐	☐	☐	☐
My operateurs is nie rekenaarvaardig nie en kan dus nie VT uitvoer nie	☐	☐	☐	☐	☐
Ek sukkel om die voorskrifte (kaarte) op die trekker gelaai te kry	☐	☐	☐	☐	☐
Ek het nie 'n goeie verteenwoordiger wat my kan help om die nodige kaarte te skryf en implementeer nie	☐	☐	☐	☐	☐

59.Voltooi asseblief die onderstaande standpunte wat u ervaring met seksiebeheer die beste beskryf:

	Verskil sterk	Verskil	Neutraal	Stem saam	Stem sterk saam
Ek besit nie die nodige toerusting om seksiebeheer te doen nie, maar sou dit gebruik as ek dit gehad het	☐	☐	☐	☐	☐
Seksiebeheer is nodig vir die skaal waarop ek boer	☐	☐	☐	☐	☐
Seksiebeheer toerusting is onbekostigbaar	☐	☐	☐	☐	☐
Seksiebeheer is minder akkuraat as wat geadverteer is	☐	☐	☐	☐	☐
Ek sou seksiebeheer byvoeg in my volgende siklus vir die vervanging van masjiene	☐	☐	☐	☐	☐

Section C: Voordele van tegnologie

Beantwoord die volgende vrae as u GPS-stuur, seksiebeheer, varieerbare toediening of al drie gebruik

60.Voltooi asseblief die volgende stellings wat die beste pas by u ervaring met veranderlike koers toepassing

	Verskil sterk	Verskil	Neutraal	Stem saam	Stem sterk saam
Die gebruik van hierdie tegnologie verhoog die opbrengs	☐	☐	☐	☐	☐
Die gebruik van hierdie tegnologie verlaag in land opbrengsvariasie	☐	☐	☐	☐	☐
Die gebruik van hierdie tegnologie bespaar brandstof	☐	☐	☐	☐	☐
Die gebruik van hierdie tegnologie bespaar saad en kunsmis	☐	☐	☐	☐	☐
Die gebruik van hierdie tegnologie verbeter werkspoed en lei tot groter produktiwiteit	☐	☐	☐	☐	☐
Die gebruik van hierdie tegnologie help drywers om meer gedoen te kry omdat dit minder inspanning vereis.	☐	☐	☐	☐	☐

61.Het u al ooit verbeterings in die kwaliteit van mielies ondervind met behulp van hierdie tegnologie?

☐ Ja ☐ Nee ☐ Weet nie

62.Wat is u beste skatting van die gevolglike opbrengstoename van die gebruik van hierdie tegnologieë?

- ☐ <3%
- ☐ 3 tot 6%
- ☐ 6 tot 10%
- ☐ 10 tot 14%
- ☐ 14 tot 20%
- ☐ Meer as 20%
- ☐ Weet nie

63.Wat is u beste skatting van die afname in land opbrengsvariasie as gevolg van die gebruik van hierdie tegnologie?

- ☐ <3%
- ☐ 3 tot 6%
- ☐ 6 tot 10%
- ☐ 10 tot 14%
- ☐ 14 tot 20%
- ☐ Meer as
- ☐Weet nie

64.As u varieerbare-toediening gebruik watter van die volgende databronne word gebruik om veranderlike koers-toepassingskaarte te genereer?

Variable Rate Decision	1. Opbrengsmonitering met GPS	2. Lug- / satelliet-infrarooi beeldmateriaal	3. Steekproefneming van die rooster	4. Groen Seeker / Weed seeker	5. Elektriese geleiding / grondskandering
Soil pH	☐	☐	☐	☐	☐
Soil fertility	☐	☐	☐	☐	☐
Seeding	☐	☐	☐	☐	☐
Besproeiing	☐	☐	☐	☐	☐

65.Wie genereer gewoonlik u veranderlike koers-toepassingskaarte?

- ☐ U self of 'n familielid
- ☐ Presisieboerdery-konsultant
- ☐ Kunsmis of chemiese handelaar
- ☐ Ander (spesifiseer)____________________

66.Hoe gereeld laat ‘n rooster-grondmonster (grid sample) van u lande neem indien van toepassing? Elke __________ jare

Section D: Beantwoord asseblief die volgende vrae rakende u boerdery databestuurstrategie

67. Op ‘n skaal van een tot tien, hoe belangrik is die bestuur van masjien versamelde data vir u boerdery? Dit sluit opbrengs- en toedieningskaarte, navigasielyne ens. In.

68. Hoe word u masjien versamelde data bestuur?

- ☐ Ek bestuur nie my majiendata aktief nie
- ☐ Ek laai dit af op ‘n stokke vir toekomstige gebruik
- ☐ Ek laai dit af op ‘n stokke en prosesseer dit met sagteware wat die vervaardiger verskaf
- ☐ Ek laai dit af op ‘n stokke en laai dit dan op ‘n internet gebaseerde platform vir verwerking en bewaring (e.g. JD Link, Operations centre, Connected farm, Field View)
- ☐ My masjien laai dit outomaties op na ‘n internet gebaseerde platform vir verwerking en bewaring (e.g. JD Link, Operations centre, Connected farm, Field View)

35 Dink u dit is belangrik om toegang tot u masjiendata te beheer? Ek neem privaatheid ernstig op

- ☐ Ja
- ☐ Nee
- ☐ Weet nie

36 Deel u tans u masjiendata met enige derde-parte?

- ☐ Ja
- ☐ Nee
- ☐ Weet nie